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A PRACTICAL TREATISE

ON THE

MANUFACTURE AND DISTRIBUTION

OF

COAL-GAS,

Its Introduction and Progressive Improvement.

ILLUSTRATED BY ENGRAVINGS FROM WORKING DRAWINGS,

WITH GENERAL ESTIMATES.

BY

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SECOND EDITION.

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TO

MY FATHER,

THIS WORK

IS APPROPRIATELY AND AFFECTIONATELY

DEDICATED.

PREFACE.

In presenting the following Work to the Public, I may preface it by a few words, stating the reasons which have induced me to compile it. I am acquainted with no work which, following the progress of the science of Gas-lighting from its first invention down to the present day, and including the numerous improvements which have of late years economized the production of gas, and facilitated its application to the wants and convenience of society, affords to the Engineer the practical statements and details which he requires in the management of Gas-works. I have endeavoured to meet this want; and in order to render my work useful, I have made it essentially *practical;* adding, by way of Introduction, a brief sketch of the history and progress of the invention. I may here observe, that my principal inducement to write this work has been the great advantage I have enjoyed in having access to, and the free use of, my Father's manuscripts and notes—the result of his long labours and experience in this department of our profession. To him I am indebted for a great mass of valuable materials. I need only add, that I have spared no pains to verify all my statements and calculations, and to obtain from the best sources the information I required.

S. C.

London, April 10th, 1841.

PREFACE TO THE SECOND EDITION.

I HAVE endeavoured in the present Edition to lay before my Readers the various improvements that have been made in the Manufacture of Gas since 1841, and I have to acknowledge the valuable assistance I have received from my friend Dr. Frankland, who has revised the chapter on the Chemistry of Coal Gas. To Dr. Lyon Playfair I am indebted for much important information; and Mr. William Pole has enabled me to perfect the subject of the Distribution of Gas through Mains, the chapter upon the theory of the motion of elastic fluids through pipes being entirely from his pen. It will be perceived that I have retained in this Edition descriptions of many portions of apparatus that have ceased to be employed: and I have done so simply that their history may be preserved, since it is often as useful to know what machinery is defective, as to be acquainted with that which is more perfect. The analysis of the various kinds of coal found in different parts of the world cannot, I think, fail to be of value. I have been careful, throughout the work, to enlarge only upon those points on which experience has enabled me to speak with certainty.

S. C.

London, April 6th, 1853.

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A PRACTICAL TREATISE

ON

THE MANUFACTURE AND DISTRIBUTION

OF

COAL-GAS.

HISTORICAL SKETCH OF THE INTRODUCTION OF LIGHTING BY COAL-GAS.

IN the earliest ages, and prior to the earliest record of events, the existence of an inflammable air appears to have been known. The perpetual fires and sacred lamps, regarded with superstition by heathens in past ages, were fed by inflammable air issuing from fissures of rocks or springs of petroleum. The fire-damp, so fatal in the experience of miners, has in modern times been discovered to be the same gas, now so valuable for the purposes of illumination.

Although both its useful and injurious properties appear thus to have been long partially known, no investigation of its nature was made, at least none published, until the end of February, 1659, when Mr. Thomas Shirley communicated to the Royal Society some experiments upon the gas issuing from a well near Wigan, in Lancashire. This paper will be found in the Philosophical Transactions for June, 1667, and I quote the interesting narrative in the quaint language of the author:—

"*Description of a Well and Earth in Lancashire, taking fire by a candle approached to it.*

"This was imparted by that ingenious and worthy gentleman, Thomas Shirley, Esq., an eye-witness of the thing now to be related in his own words, viz.:—

"About the latter end of February, 1659, returning from a journey to my house in Wigan, I was entertained with a relation of an odd spring situated in one Mr. Hawk-

ley's ground (if I mistake not), about a mile from the town, in that road which leads to Warrington and Chester.

"The people of this town did confidently affirm that the water of the spring did burn like oyle; into which error they suffered themselves to fall for want of due examination of the following particulars.

"For when we came to the said spring (being five or six in company together) and applied a lighted candle to the surface of the water, 'tis true there was suddenly a large flame produced, which burnt vigorously; at the sight of which they all began to laugh at me for denying what they had positively asserted; but I, who did not think myself confuted by a laughter grounded upon inadvertency, began to examine what I saw; and observing that this spring had its eruption at the foot of a tree growing on the top of a neighbouring bank, the water of which spring filled a ditch that was there, and covered the burning place lately mentioned; I then applied the lyghted candle to divers parts of the water contained in the said ditch, and found, as I expected, that upon the touch of the candle and the water the flame was extinct.

"Again, having taken up a dishful of water at the flaming place and held the lighted candle to it, it went out; yet I observed the water at the burning place did boyle and heave like water in a pot upon the fire, though my hand put into it perceived it not so much as warm.

"This boyling I conceived to proceed from the eruption of some bituminous or sulphureous fumes, considering this place was not above thirty or forty yards distant from the mouth of a coal-pit there; and indeed Wigan, Ashton, and the whole country for many miles' compass, is underlaid with coal. Then, applying my hand to the surface of the burning place of the water, I found a strong breath, as it were a wind, to bear against my hand.

"Then I caused a dam to be made, and thereby hindering the recourse of fresh water to the burning place, I caused that which was already there to be drained away; and then applying the burning candle to the surface of the dry earth at the same point where the water burned before, the fumes took fire and burnt very bright and vigorous; the cone of the flame ascended a foot and a half from the superficies of the earth: the basis of it was of the compass of a man's hat about the brim. I then caused a bucket full of water to be poured on the fire, by which it was presently quenched, as well as my companions' laughter was stopped, who began to think the water did not burn.

"I did not perceive the flame to be discoloured like that of sulphureous bodies, nor to have any manifest scent with it. The fumes, when they broke out of the earth and prest against my hand, were not, to my best remembrance, at all hot."

The next mention we find of the presence of an "elastic inflammable air" in coal is in the account of some experiments made by Dr. Stephen Hales, for the production of elastic fluids from a great number of substances, and are related in the first volume of his 'Vegetable Statics,' published in 1726.

In 1733 Sir James Lowther communicated a paper to the Royal Society upon the damp air issuing from the shaft of a coal-mine near Whitehaven. After his men had sunk the pit to the depth of forty-two fathoms, instead of finding water as they expected, they were surprised by a rush of air, which caught fire on a candle being held towards it: it burned very fiercely with a flame about one yard in diameter and two yards high, which frightened the workmen so that they immediately went up the pit, after extinguishing the flame by beating it out with their hats. The steward of the works being made acquainted with the circumstance, went down the pit himself, and again lighted the air, which had increased in volume; it burned fiercely as before, the flame being blue at the bottom and more white towards the top: they then extinguished it in the same manner, made a greater opening in the black stone bed, and again fired the air: the flame was a full yard in diameter and about three yards high, and soon heated the pit to so great a degree that they made all possible haste to put out the flame, which this time could only be effected with the assistance of a spout of water. It was found necessary to make a tube to carry off the inflammable air; this tube projected four feet above the top of the pit, and through it the gas discharged itself, without sensibly diminishing in its strength or lessening in its quantity during the two years that elapsed between the sinking of the shaft and Sir James Lowther's report to the Royal Society. Bladders were filled with gas from this tube, which were carried away, and the gas burned through a small pipe inserted in the bladder.

The Rev. Dr. John Clayton, dean of Kildare, made some experiments on the "spirit of coal;" he was one of the first who actually distilled coal in a close vessel, and burned the gas thus obtained from the bladders in which it was collected. These experiments are related in the Philosophical Transactions for 1739, in an extract from a letter by the Rev. Dr. John Clayton, as follows:—

"Having seen a ditch within two miles of Wigan, in Lancashire, wherein the water would seemingly burn like brandy, the flame of which was so fierce that several strangers have boiled eggs over it; the people thereabouts, indeed, affirm that about thirty years ago it would have boiled a piece of beef; and that whereas much rain formerly made it burn fiercer, now, after rain, it would scarcely burn at all. It was after a long-continued season of rain that I came to see the place and make some experiments; and found accordingly, that a lighted paper, though it were waved all over the ditch, the water would not take fire. I then hired a person to make a dam in the ditch and fling out the water, in order to try whether the steam which arose out of the ditch would then take fire, but found it would not. I still, however, pursued my experiment, and made him dig

deeper; and when he had dug about the depth of half a yard, we found a shelly coal, and the candle being then put down into the hole, the air catched fire and continued burning.

"I got some coal and distilled it in a retort in an open fire. At first there came over only phlegm, afterwards a black *oil*, and then, likewise, a *spirit* arose which I could no ways condense; but it forced my lute and broke my glasses. Once, when it had forced my lute, coming close thereto, in order to try to repair it, I observed that the spirit which issued out, caught fire at the flame of the candle, and continued burning with violence as it *issued out* in a *stream*, which I blew out and lighted again alternately several times. I then had a mind to try if I could save any of this spirit, in order to which I took a turbinated receiver, and putting a candle to the pipe of the receiver, whilst the spirit arose, I observed that it catched flame, and continued burning at the end of the pipes, though you could not discern what fed the flame. I then blew it out and lighted it again several times; after which I fixed a bladder, squeezed and void of air, to the pipe of the receiver; the oil and phlegm descended into the receiver, but the spirit, still ascending, blew up the bladder. I then filled a good many bladders therewith, and might have filled an inconceivable number more, for the spirit continued to rise for several hours, and filled the bladders almost as fast as a man could have blown them with his mouth, and yet the quantity of coals distilled was inconsiderable. I kept this spirit in the bladders a considerable time, and endeavoured several ways to condense it, but in vain; and when I had a mind to divert strangers or friends, I have frequently taken one of these bladders and pricked a hole therein with a pin, and compressing gently the bladder near the flame of a candle till it once took fire, it would then continue flaming till all the spirit was compressed out of the bladder; which was the more surprising, because no one could discern any difference in the appearance between these bladders and those which are filled with common air."

During the long period that elapsed between the years 1739 and 1792 many experiments were made upon inflammable air, merely as a subject of philosophical curiosity, without their being attended by any useful or practical results.

To the talent of Mr. Murdoch we owe the first introduction of gas as a source of economical light, and to him must be awarded the great merit of having first arranged an apparatus for the production of gas, so as to render it useful to mankind. Of the value of the adaptation of gas to the purposes of illumination no one can doubt: gas-lighting must indeed be placed amongst the greatest of the various improvements which ingenuity has introduced into the arts of civilized life.

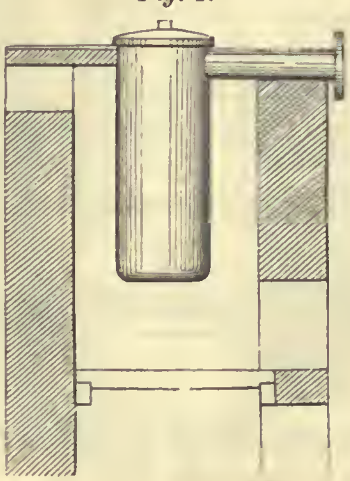
It is not many years since our streets were dimly lighted by miserable oil-lamps, that only served to make the surrounding gloom more perceptible; the shades of night offered an easy escape to depredators, by whom the metropolis was infested. Now, on the contrary, by the brilliant lustre of the gas, night is rendered as secure

as day, and the inhabitants may pursue their various avocations by its cheerful light, prolonging the period of their usefulness and activity. Those only who have experienced the contrast can appreciate the immense advantage arising from the present system. When we consider the great increase of pleasure and convenience thus afforded us, we must feel deeply indebted to those highly-gifted and enterprising individuals, by whose talents and industry so great a blessing has been conferred on society.

In the year 1792 Mr. Murdoch made use of gas in lighting his house and office at Redruth, in Cornwall, where he then resided. The mines at which he worked being distant some miles from his house, he was in the constant practice of filling a bladder with coal-gas, in the neck of which he fixed a metallic tube, with a small orifice, through which the gas issued; this being ignited, served as a lantern to light his way for the considerable distance he had nightly to traverse. This mode of illumination being then generally unknown, it was thought by the common people that magical arts alone could produce such an effect. At this time inflammable air seems to have been similarly used by a French gentleman of the name of Le Bon, who lighted his house and gardens with gas obtained from wood and coal; but this was not known to Mr. Murdoch, nor was the first result improved upon in France, and it remained for Mr. Murdoch to proceed with his invention alone.

In 1798 Mr. Murdoch erected an apparatus for the production of gas at the manufactory of Messrs. Boulton and Watt at Soho. The annexed sketch (Fig. 1*) will show the description of retort he then used.

Fig. 1.



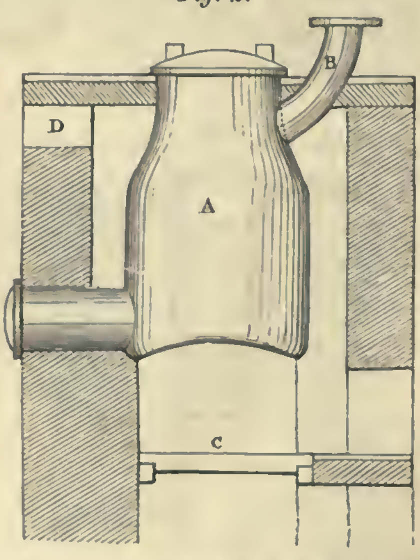
* The figures are drawn to a scale of half an inch to the foot. The same letters refer to corresponding parts in all.

In March, 1802, on occasion of the general illuminations for the Peace of Amiens, Mr. Murdoch first publicly exhibited the gas-light, by placing at each end of the Soho manufactory what was termed a Bengal light. The operation was simply effected by fixing a retort in the fireplace of the house below, and then conducting the gas issuing from thence into a copper vase. This was the only gas used on that occasion, the rest of the manufactory being illuminated by the usual small glass oil-lamps, and not with the gas, as has been erroneously stated*.

About a year after this the Soho Foundry was lighted. The apparatus for producing and distributing the gas was of a crude description, although at the time it was considered perfect. The gas from the retort was conveyed at once to a gas-holder, containing about 300 cubic feet, and from thence in brazed copper-tubes to the rude cock-spur burners. Mr. Murdoch afterwards repeatedly varied the form of his retorts; he found it inconvenient to extract the coke from his first, and therefore constructed them in the forms shown in the following figures.

In Fig. 2, A is the retort; B, the pipe that conveys away the gas; C, the furnace; and D, the flue leading to the chimney. The disadvantages found attendant upon this form will be evident; the coal, acted upon in such a mass, became encrusted with an outside coat of carbon, which prevented the effect of the heat from penetrating quickly to the interior.

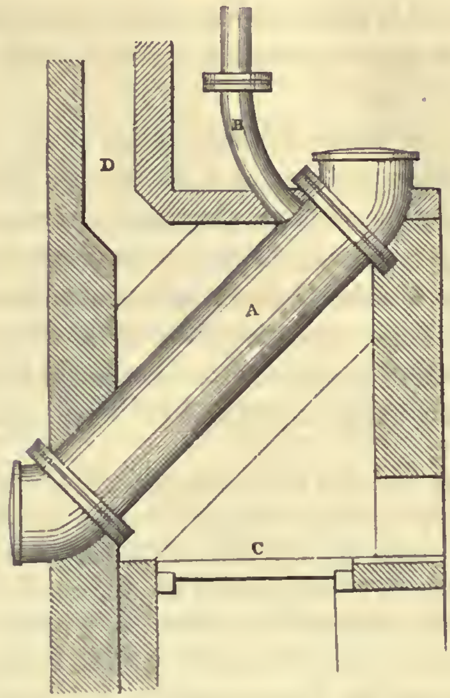
Fig. 2.



The form of Fig. 3 was more economical than that of the retort above mentioned, but not so much so as that of Fig. 4.

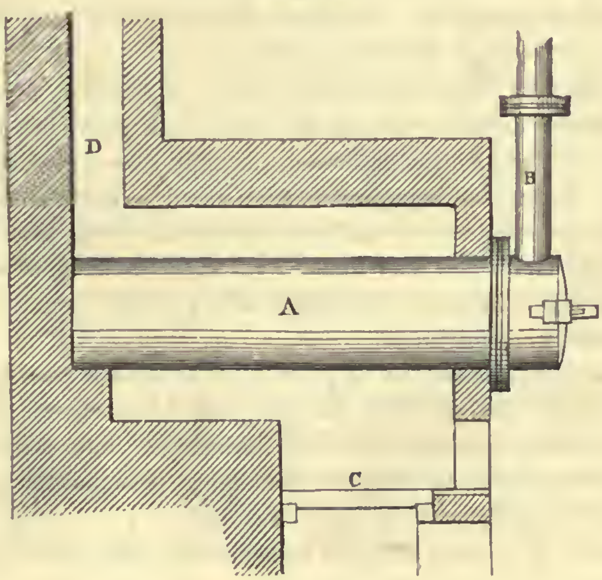
* Mr. Clegg, then a pupil of Messrs. Boulton and Watt, was present and assisted at this illumination.

Fig. 3.



Mr. Murdoch varied the transverse section of this last from cylindrical to oval and ear-shaped, but retained the position and mode of setting.

Fig. 4.



In 1805 Mr. Murdoch lighted the extensive cotton-mills of Messrs. Phillips and Lee, of Salford; but still in so defective a manner, that siphons were placed along the pipes conveying the gas, to collect the tar that condensed in them; nor was the gas at all purified by lime.

The retort he used was similar in shape to that of Fig. 2, but made to contain 15 cwt. of coal, and without the opening at the bottom. The coal was introduced by means of a cage, lifted by a small crane, which cage also served the purpose of withdrawing the coke. This retort was attended by the disadvantages already described.

The following is Mr. Murdoch's simple and minute account of this apparatus, read before the Royal Society, February 25th, 1805. It is entitled, "An Account of the Application of the Gas from Coal to economical Purposes, by Mr. William Murdoch, communicated by the Right Hon. Sir Joseph Banks, Bart."

"The facts and results intended to be communicated in this paper are founded upon observations made during the present winter at the cotton manufactory of Messrs. Phillips and Lee, at Manchester, where the light obtained by the combustion of the gas from coal is used upon a very large scale; the apparatus for its production and application having been prepared by me at the works of Messrs. Boulton, Watt, and Co., at Soho.

"The whole of the rooms of this cotton-mill, which is, I believe, the most extensive in the United Kingdom, as well as its counting-house and store-rooms, and the adjacent dwelling-house of Mr. Lee, are lighted with the gas from coal. The total quantity of light used during the hours of burning has been ascertained, by a comparison of shadows, to be about equal to the light which 2000 mould candles of six in the pound would give; each of the candles with which the comparison was made, consuming at the rate of four-tenths of an ounce (175 grains) of tallow per hour.

"The quantity of light is necessarily liable to some variation, from the difficulty of adjusting all the flames so as to be perfectly equal at all times; but the admirable precision and exactness with which the business of this mill is conducted, afforded as excellent an opportunity of making the comparative trials I had in view, as is perhaps likely to be ever obtained in general practice; and, the experiments being made upon so large a scale, and for a considerable period of time, may, I think, be assumed as a sufficiently accurate standard for determining the advantages to be expected from the use of the gas-lights under favourable circumstances.

"It is not my intention in the present paper to enter into a particular description of the apparatus employed for producing the gas; but I may observe generally, that the coal is distilled in large iron retorts, which, during the winter season, are kept constantly at work, except during the intervals of charging; and that the gas, as it rises from them, is conveyed by iron pipes into large reservoirs, or gasometers, where it is washed and purified, previous to its being conveyed through other pipes, called mains, to the mills.

"These mains branch off into a variety of ramifications (forming a total length of several miles) and diminish in size, as the quantity of gas required to be passed through them becomes less. The burners, where the gas is consumed, are connected with the above mains by short tubes, each of which is furnished with a cock to regulate the admission of the gas to each burner, and to shut it totally off when requisite. This latter operation may likewise be instantaneously performed throughout the whole of the burners in each room, by turning a cock with which each main is provided near its entrance into the room. The burners are of two kinds; the one is upon the principle of the Argand lamp, and resembles it in appearance; the other is a small curved tube with a conical end, having three circular apertures, or perforations, of about a thirtieth of an inch in diameter; one at the point of a cone, and two lateral ones, through which the gas issues, forming three divergent jets of flame, somewhat like a *fleur-de-lis*. The shape and general appearance of this tube has procured it, among the workmen, the name of the cockspur burner.

"The number of burners employed in all the buildings amount to 271 Argands and 633 cockspurs, each of the former giving a light equal to that of four candles of the description above-mentioned, aud each of the latter a light equal to two and a quarter of the same candles. When thus regulated, the whole of the above burners require an hourly supply of 1250 cubic feet of the gas produced from cannel coal; the superior quality and quantity of the gas produced from that material having given it a decided preference in this situation over every other coal, notwithstanding its higher price.

"The time during which the gas-light is used may, upon an average of the whole year, be stated at least at two hours per day of twenty-four hours. In some mills where there is over-work it will be three hours; and in the few where night-work is still continued, nearly twelve hours. But, taking two hours per day as the common average throughout the year, the consumption in Messrs. Phillips and Lee's mill will be $1250 \times 2 = 2500$ cubic feet of gas per day; to produce which seven hundredweight of coal is required in the retorts. The price of the best Wigan cannel (the sort used) is $13\frac{1}{2}$*d.* per cwt. (22*s.* 6*d.* per ton) delivered at the mill; or say about eight shillings for the seven hundredweight. Multiplying by the number of working days in the year (313), the annual consumption of cannel will be 110 tons, and its cost £125.

"About one-third of the above quantity, or say forty tons of good common coal, value 10*s.* per ton, is required for fuel to heat the retorts; the annual amount of which is £20.

"The 110 tons of cannel coal, when distilled, produce about 70 tons of good coke, which is sold upon the spot at 1*s.* 4*d.* per cwt., and will therefore amount annually to the sum of £93.

"The quantity of tar produced from each ton of cannel coal is from eleven to twelve ale gallons, making a total annual produce of about 1250 ale gallons, which not having been yet sold, I cannot determine its value: but whenever it comes to be manufactured in large quantities, it cannot be such as to influence the economical statement, unless, indeed, new applications of it should be discovered.

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"The quantity of aqueous fluid which came over in the course of the observations which I am now giving an account of, was not exactly ascertained, from some springs having got into the reservoir; and as it has not been yet applied to any useful purpose, I may omit further notice of it in this statement.

"The interest of the capital expended in the necessary apparatus and buildings, together with what is considered as an ample allowance for wear and tear, is stated by Mr. Lee at about £550 per annum, in which some allowance is made for this apparatus being made upon a scale adequate to the supply of a still greater quantity of light than he has occasion to make use of.

"He is of opinion that the cost of attendance upon candles would be as much, if not more, than upon the gas apparatus; so that in forming the comparison, nothing need be stated upon that score on either side.

"The economical statement for one year stands thus:—

Cost of 110 tons of cannel coal - - - - - - -	£125
„ 40 „ common - - - - - - -	20
	145
Deduct the value of 70 tons of coke - - - - - -	93
The annual expenditure in coal, after deducting the value of the coke, and without allowing anything for the tar, is therefore - -	52
And the interest of capital, and wear and tear of apparatus - -	550

making the total expense of the gas apparatus about £600 per annum.

"That of candles to give the same light would be about £2000, each candle consuming at the rate of 4-10ths of an ounce of tallow per hour; the 2500 candles burning upon an average of the year two hours per day, would, at one shilling per pound (the present price), amount to nearly the sum of money above-mentioned.

"If the comparison were made upon an average of three hours per day, the advantage would be still more in favour of the gas-light, the interest of the capital and wear and tear of the apparatus continuing nearly the same as in the former case; thus $1250 \times 3 = 3750$ cubic feet of gas per day, which would be produced by 10¾ cwts. of cannel coal, thus multiplied by the number of working days, gives 168 tons per annum, which, valued as before, amounts to - - - - - - - - - £188

And 60 tons of common coal for burning under the retorts will amount to	30
	218
Deduct 105 tons of coke at 26*s*. 8*d*. - - - - - - - -	140
Leaving the expenditure of coal, after the deduction of the coke, and without allowance for the tar, at - - - - - - - -	78

Adding to which the interest and wear and tear of apparatus as before, the total annual cost will not be more than £650, whilst that of tallow, rated as before, will be £3000.

"It will readily occur that the greater number of hours the gas is burnt, the greater will be its comparative economy; although in extending it beyond three hours an increase of some parts of the apparatus would be necessary. If the economical comparison were made with oils, the advantages would be less than with tallow.

"The introduction of this species of light into the establishment of Messrs. Phillips and Lee has been gradual, beginning at the year 1805 with two rooms of the mills, the counting-house, and Mr. Lee's dwelling-house; after which it was extended through to the whole manufactory as expeditiously as the apparatus could be prepared. At first some inconvenience was experienced from the smell of the unconsumed or imperfectly purified gas, which may in a great measure be attributed to the introduction of successive improvements in the construction of the apparatus as the work proceeded. But since its completion, and since the persons to whose care it is confided have become familiar with its management, this inconvenience has been obviated, not only in the mill, but also in Mr. Lee's house, which is most brilliantly illuminated with it, to the exclusion of every other species of artificial light.

"The peculiar softness and clearness of this light, with its almost unvarying intensity, have brought it into great favour with the work-people; and it being free from the inconvenience and danger resulting from the sparks and frequent snuffing of candles, is a circumstance of material importance, as tending to diminish the hazard of fire, to which cotton-mills are known to be much exposed.

"The above particulars, it is conceived, contain such information as may tend to illustrate the general advantages attending the use of the gas-light; but, nevertheless, the Royal Society may perhaps not deem it uninteresting to be apprised of the circumstances which generally gave rise in my mind to its application as an economical substitute for oils and tallow.

"It is now nearly sixteen years since, in a course of experiments I was making at Redruth, in Cornwall, upon the quantities and qualities of the gases produced by distillation from different mineral and vegetable substances, I was induced, by some observations I had previously made upon the burning of coal, to try the combustible property of the gases produced from it, as well as from peat, wood, and other inflammable substances; and being struck with the great quantities of gas which they afforded, as well as with the brilliancy of the light and the facility of its production, I instituted several experiments with a view of ascertaining the cost at which it might be obtained, compared with that of equal quantities of light yielded by oils and tallow.

"My apparatus consisted of an iron retort with tinned copper and iron tubes, through which the gas was conducted to a considerable distance, and there, as well as at intermediate points, was burned through apertures of various forms and dimensions. The experiments were made upon coal of different qualities, which I procured from distant parts of the kingdom, for the purpose of ascertaining which would give the most economical results. The gas was also washed with water, and other means were employed to purify it.

"In the year 1798 I removed from Cornwall to Messrs. Boulton, Watt, and Co.'s works for the manufactory of steam-engines, at the Soho Foundry, and there I constructed an apparatus upon a larger scale, which, during many successive nights, was applied to the lighting of their principal building, and various new methods were practised of washing and purifying the gas. These experiments were continued, with some interruptions, until the peace of 1802, when a public display of this light was made by me in the illumination of Mr. Boulton's manufactory at Soho upon that occasion.

"Since that period I have, under the sanction of Messrs. Boulton, Watt, and Co., extended the apparatus at Soho Foundry, so as to give light to all the principal shops, where it is in regular use, to the exclusion of other artificial light; but I have preferred giving the results of Messrs. Phillips and Lee's apparatus, both on account of its greater extent, and the greater uniformity of the lights, which rendered the comparison with candles less difficult. At the time I commenced my experiments I was certainly unacquainted with the circumstance of the gas from coal having been observed by others to be capable of combustion, but am since informed that the current of gas escaping from Lord Dundonald's tar ovens had been frequently fired; and I find that Dr. Clayton, in a paper in Volume XII. of the Transactions of the Royal Society, so long ago as the year 1739, gave an account of some observations and experiments made by him, which clearly manifests his knowledge of the inflammable property of the gas, which he denominates 'the spirit of coals;' but the idea of applying it as an economical substitute for oils and tallow does not appear to have occurred to this gentleman; and I believe I may, without presuming too much, claim both the first idea of applying, and the first actual application of this gas to economical purposes."

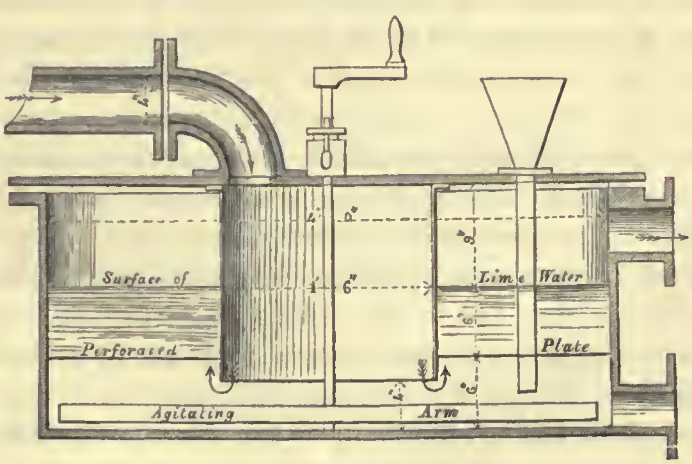
In Mr. Clegg's Journal, which I have before me, it is stated that the cotton-mill of Mr. Henry Lodge at Sowerby Bridge, near Halifax, was lighted with gas a fortnight before that of Messrs. Phillips and Lee; Mr. Clegg had made his men work over-time in order that his apparatus might be the first completed, there being a friendly spirit of emulation between Mr. Murdoch and his pupil in advancing the progress of gas-lighting.

The gas burned in these establishments retained all its impurities, and it became evident that, unless some plan were adopted to purify it, it could not be burnt in close rooms, the offensive effluvia causing headache, and even in some cases affecting the lungs. To remedy this serious evil, Mr. Clegg, in the next manufactory he lighted (that of Mr. Harris, of Coventry) introduced lime into the tank of the gas-holder, preventing it from settling at the bottom by an agitator, put in motion from time to time. A condenser was also added to the apparatus, for, in those previously erected, as has already been observed, siphons had to be placed at intervals along the services to draw off the condensed oil and tar. This

condenser was a prolongation (in a series of vertical bends) of the pipe between the retorts and the gas-holder, which, terminating an inch or two beneath the lime-water in the gas-holder tank, bubbled up through it, and became partially purified. This plan was found to answer tolerably well for a short time, but the difficulty of removing the spent lime from the tank formed a practical obstacle to its further adoption.

Among the various places lighted with gas about this time (1807, 1808), the Catholic college of Stonyhurst, Lancashire, deserves particular mention. This establishment was the first of the kind that adopted the use of gas-lights, and Mr. Clegg received great encouragement in making experiments and improving his apparatus, from the liberality and kindness of the Professors of the college. He was well aware that gas could not with safety be applied to lighting private rooms unless it were perfectly freed from sulphuretted hydrogen, and that the method adopted at Coventry would not answer the purpose, on account of the difficulty attending the removal of the lime. Lime-water was therefore introduced into a separate vessel, in which the lime could be easily renewed; the gas was passed through this vessel previous to its entering the gas-holder, and was by this means rendered perfectly pure. The vessel is shown in the annexed wood-cut (Fig. 5).

Fig. 5.



After completing this apparatus, Mr. Clegg invited Dr. Henry to visit Stonyhurst College, to examine the method he had there adopted for purifying, and to test the gas. Dr. Henry had previously made some chemical experiments re-

specting the affinity of lime for sulphuretted hydrogen, but gave it as his opinion that "coal-gas could not be purified from sulphuretted hydrogen, on a large scale, by means of lime." I presume this opinion to have been founded upon the idea of the practical difficulties attendant upon the complete contact necessary to produce combination to any great extent; for his own experiments in the laboratory proved that lime would combine with sulphuretted hydrogen, leaving the carburetted hydrogen free. Dr. Henry refused to acknowledge the efficacy of Mr. Clegg's apparatus for purifying, until he had repeatedly tested the gas; after which he admitted it to be perfectly satisfactory, and capable of being adopted in large manufactories.

In 1808 Dr. Henry communicated a paper to the Royal Society, claiming as his own idea the use of lime-water for the purification of gas from sulphuretted hydrogen in large quantities, without even mentioning the apparatus of Mr. Clegg, who, having consulted Dr. Henry while proceeding with his experiments at Stonyhurst, felt much pain as well as disappointment at this injustice, which was the more unexpected, from the friendship that had subsisted between them. After this, Messrs. Boulton and Watt erected a lime machine at the Soho manufactory.

While these circumstances were passing in the country, Mr. Winsor was lecturing at the Lyceum Theatre in London, claiming the *invention* of gas-lighting, and exhibiting a few lamps in Pall Mall, by way of specimen. Though exceedingly deficient in practical and chemical knowledge, he was indefatigable as a projector; and if we are indebted to Mr. Murdoch for the first practical introduction of gas-lighting, we owe the formation of the first Gas-light Company to Mr. Winsor.

In the year 1809 application was made to Parliament for an Act to incorporate a Company, to be called "The London and Westminster Chartered Gas-light and Coke Company." The object of the persons desirous of forming this Company was to carry out effectually the operations commenced in Pall Mall, but many were the difficulties they had to encounter. Their projects were considered visionary; great prejudices were also entertained against the general introduction of gas-lighting, from the idea of its being fraught with danger; the Act was also opposed by Mr. Watt and Mr. Murdoch, on the plea that the latter gentleman, having been the first to suggest the idea of gas being used as a source of economical light, had a right to the exclusive privilege of its application. In consequence of these various objections, the Bill was thrown out. The interest however of too many persons was at stake to suffer them to be easily discouraged in

their scheme: in the following year, 1810, after again incurring considerable expense, and combating much opposition, they succeeded in their object, and an Act was passed, authorizing his Majesty to grant a charter within three years. It is unnecessary to enter here into the details of the stipulation and conditions; they will be found in the printed Parliamentary Reports for the year 1810.

In the meanwhile many cotton-mills in Lancashire had been lighted with gas, and, among the rest, the extensive manufactory belonging to Mr. Greenaway, of Manchester, where Mr. Clegg invented and put in practice the hydraulic main, a contrivance since universally adopted, with hardly a deviation from the original design. In 1812 he lighted the cotton-mills of Mr. Samuel Ashton and Brothers, at Hyde, near Stockport, where the lime machine was introduced with increased effect. Here twelve-inch cylindrical retorts and improved mouth-pieces were first introduced; the mechanism was also first attached to the gas-holder for regulating its specific gravity.

In the same year Mr. Clegg lighted Mr. Ackerman's premises in the Strand. Gas-lights, being then a novelty, created much surprise and admiration; indeed, a lady of rank was so much astonished and delighted with the brilliancy of a lamp fixed on the shop-counter, that she begged to be allowed to carry it home in her carriage, offering any sum for a lamp so far superior to any she had before seen: this is a proof how little the nature of gas-lighting was at that time understood. The great success of the plan pursued in lighting this establishment was the cause of Mr. Clegg's being engaged as engineer to the Chartered Gas-light and Coke Company.

When the gas apparatus at Mr. Ackerman's had been at work some time, a fear was entertained of its having to be discontinued, from the great complaints that arose of the refuse lime-water running into the main sewer. To remedy this evil, the use of dry lime was substituted; but this plan was afterwards abandoned, on account of the quantity of lime it required: it was not then known that a great extent of surface was necessary.

From the time of the formation of the Chartered Gas-light and Coke Company to the year 1813 (when Mr. Clegg was engaged as engineer), the works had been entrusted to Messrs. Winsor, Accum, and Hargraves. It will appear an enigma at the present day how their attempts to construct a gas apparatus could so utterly have failed; but discredit is not attached to those gentlemen, for it must be remembered that nothing had yet been done to which reference could be made—all was new: every machine had to be *invented*, and the workmen instructed in its use.

Much time and money had consequently been uselessly expended, and at this time (1813) the Company was nearly on the point of dissolution. Mr. Clegg having been educated an engineer at Messrs. Boulton and Watt's establishment the various resources of his profession were familiar to him, and having already had much experience in lighting private establishments with gas, it may be conceived that the affairs of the Company were conducted with more skill and judgement than hitherto; but still, though the concern was now put in a better train, many difficulties had to be encountered and overcome, and additional expenses to be incurred, before the Company could expect to receive any return for their immense outlay. The existing apparatus was discarded, being perfectly useless, and new machines were constructed on an improved plan.

The great prejudice entertained against the introduction of gas-lighting, not only by the public but also by men of science, seemed at one time to present an insurmountable obstacle to its further progress. Lighting a town with gas was still thought a visionary scheme. Sir Humphry Davy considered the idea so ridiculous, that he asked "if it were intended to take the dome of St. Paul's for a gasometer?" To which Mr. Clegg replied, that he hoped to see the day when gasometers would not be much less. They are now (1852) made 150 feet in diameter.

The Gas Company at first fitted up and supplied shops and houses with gas free of expense, in order to induce others to adopt the plan; so things went on for nearly two years, with only a few retorts in action. It was strangely believed that the pipes conveying the gas must be hot! When the passages to the House of Commons were lighted, the architect insisted upon the pipes being placed four or five inches from the wall, for fear of fire; and the curious would apply the gloved hand to the pipe to ascertain the temperature. Mr. Maiben (a Scotch gentleman, I believe), who had erected several small apparatus, took out a patent for gas-pipes made of wood and paper. So great was the difficulty of obtaining service-pipes, that they were also formed of old musket-barrels attached to each other, the muzzle of one being screwed into the breach of the next. It was some time before the manufacturers could be prevailed upon to make welded tubes for gas-pipes.

The Insurance Companies also started objections, such as this: "If a burner were by carelessness left open, what would be the consequence?" To obviate this fresh obstacle, Mr. Clegg invented the burner described hereafter, which answered the purpose of overcoming the opposition of the Insurance Companies, though, from the expense of manufacturing such burners, they were never afterwards used.

In 1813 Mr. Clegg commenced the Gas-works at Peter-street, Westminster.

The ground on which they were erected was a swamp, nearly on a level with the Thames, and formerly overflowed by the river; it was therefore impossible to sink for a tank, and an iron one was then very expensive; this gave rise to Mr. Clegg's revolving gasholder, which worked with greater regularity and less friction than any other; but the expense of construction was as great as that of an iron tank; it was besides complicated and difficult to repair.

After the works at Peter-street had been some time in operation, Sir Joseph Banks and several other members of the Royal Society were deputed to examine and report upon the gas apparatus. The deputation strongly recommended Government to oblige the Company to employ gas-holders containing not more than 6000 cubic feet, secured in strong buildings. As Sir Joseph Banks and some of the other members of the deputation were in the gasometer-house, conversing upon the danger of a leak in the gas-holder if a light happened to be near, Mr. Clegg called to a man, and desired him to bring a pickaxe and candle: he then struck a hole in the side of the vessel, and applied the light to the issuing gas, to the no small alarm of all present, most of whom quickly retreated: contrary to their expectation, no explosion resulted from this experiment. This practical proof however did not serve to convince them of their error, and the Chartered Gas Company was put to considerable expense in making small gas-holders, surrounded by strong buildings.

From the first introduction of gas-lighting the use of large gas-holders was considered as highly dangerous. After Stonyhurst had been lighted (where the capacity of the gas-holder was 1000 cubic feet), Mr. Wright, the Superior of the College, complimented Mr. Clegg upon his success in lighting the establishment with gas, but suggested as an improvement the alteration of the size of the gas-holder: he thought that one of 1000 cubic feet was too unwieldy, and advised that two should be erected to contain 500 feet each. Telescopic gas-holders were invented twenty years before they were brought into use; and gas-holders without a house to protect them from the weather were thought absurd: those erected by Mr. Clegg at Chester and Birmingham were much disapproved of on account of their being exposed, and the Chartered Company for years pursued the plan of erecting buildings over them.

At the end of 1813 an explosion of a serious nature took place at the Westminster station, owing to a volume of gas escaping from the purifier, which was placed in a building near the retort-house, coming in contact with the flues of the retorts. The windows of several houses in the neighbourhood were shattered, and

Mr. Clegg was severely injured. The recurrence of such an event was afterwards effectually guarded against, by drawing the refuse lime-water through a bent pipe, always containing sufficient water to seal it. The fear however of such an explosion again occurring made the public timid for some time.

On the 31st of December, 1813, Westminster Bridge was lighted with gas. It soon became an object of attraction, and, while the novelty lasted, was a fashionable promenade. The lamp-lighters were much startled with the new system, and refused to act, and Mr. Clegg had himself to light the lamps for a few nights.

The first parish that applied for a contract to have their streets lighted with gas was St. Margaret's, Westminster; and on the 1st of April, 1814, the old oil-lamps were removed, and the more brilliant gas-lights substituted in their stead. Hundreds of people used to follow the lamp-lighter in his rounds, to watch his operations. Torches for the purpose of lighting the lamps were afterwards dispensed with, and the hand-lantern introduced by Mr. Grafton was substituted.

The contractors who had supplied the oil-lamps were loud in their complaints. One of these, when told by the Board of Guardians that his lamps gave no light, replied that this was not in his contract, which only stated that they were to be *lighted* from sunset to sunrise. This was literally the case,—*lighted* they were, but *light* they gave none.

At the outset it was not easy to overcome the prejudice in favour of the brackets attached to the houses; it was after much altercation between the Gas Companies and the parish authorities that the present posts were allowed. When the Chartered Gas Company had surmounted the principal difficulties, other Companies began to erect gas-apparatus in different parts of the kingdom; and Mr. Clegg was engaged to light Bristol, Birmingham, Chester, Kidderminster, Worcester, etc. At the present time there is scarcely a town in Great Britain that is not lighted with gas. The first retorts erected at Peter-street were much superior to the present mode of setting, as far as regarded the health and comfort of the workmen: a flue was attached over the mouth-pieces, to convey the smoke and flame directly into the chimney; but this flue being found expensive was abandoned. The retorts were set two to a fire, one over the other; this plan required less fuel to carbonize the coal than any since adopted; but again it was more expensive, and occupied a greater space than the oven plan adopted by Mr. Rackhouse. It would be superfluous to mention the variations in the shape of retorts, with different numbers in an oven, from three to thirteen: almost every gas engineer has a plan of his

own; and as long as the coal is allowed to be distilled in bulk, the slight variation in shape and number in an oven is of little consequence.

On the occasion of the illumination for the Peace of June 1814, when the Allied Sovereigns visited England, the devices in gas-lights far exceeded in splendour anything before or since exhibited; the principal illumination was a Pagoda, erected by order of Government in St. James's Park. This Pagoda was octagonal, composed of wood, eighty feet high, at each angle of which a perforated perpendicular pipe was fixed; a projecting pipe was also placed at every angle of each story, in the form of a griffin's head, pierced with small holes, through which issued jets of gas. At the lowest orifice of each perpendicular pipe a small oil-lamp was concealed, which, when lighted, ignited the first jet of gas; this communicated the light to the next jet, and so on to the summit. The burners of each angle were thus simultaneously ignited, and the gas-light rose into the air with the majesty of a rocket; and the Pagoda (illuminated by more than ten thousand burners) was fired in a few seconds, the whole appearing like a mass of living light. This device was fortunately exhibited to the Prince Regent and most of the Royal Family at their request on the night previous to the general illumination; their Highnesses walked in Carlton Gardens to witness the effect, and expressed great approbation. The night on which this first grand display of gas-lighting was to have been exhibited to the public, Sir William Congreve, contrary to Mr. Clegg's advice and request, insisted upon letting off fireworks from the Pagoda before the gas should be turned on; the consequence was, that the whole erection was burnt to the ground. The accident was not only mortifying on account of the expense and trouble incurred by the Gas Company in this affair, but still more unfortunate, as gas-lighting had been only lately introduced, and had many enemies. A report was spread abroad the following day that the gas had set fire to the Pagoda: the public were never entirely undeceived.

In 1815 Guildhall was lighted with gas. The following paragraph is extracted from one of the papers of the day:—

"Lord Mayor's Day.—Yesterday this annual ceremony was celebrated with more than usual display; but the great and striking attraction was the renovated appearance of Guildhall. It would not be easy to conceive a more imposing spectacle than was presented when the whole company sat down to dinner. The profuse delicacies of the table, the waving feathers and sparkling jewels of the ladies, the mild splendour of the gas, shedding a brightness clear as summer's noon, but undazzling and soft as moonlight, altogether formed a magnificent combination worthy the inauguration of the presiding

citizen of the great city. Those who have been used only to the brilliancy of oil and candle-light can have no adequate idea of the effect of an illumination by gas. It so completely penetrates the whole atmosphere, and at the same time is so genial to the eyesight, that it appears as natural and pure as daylight, and it sheds also a warmth as purifying to the air as cheering to the spirits."

At this period in the progress of gas-lighting the gas was sold at 15*s.* per thousand cubic feet, but the promoters received no dividend; all the rents were absorbed in new works, and in the struggle to produce better results. But the expense of construction was enormous compared to what it is at present. Gas-holders were looked upon as reservoirs of explosive matter, and it was considered advisable that they should not be allowed to contain more than 6000 cubic feet, and be surrounded by strong brick buildings. The first gas-holders were however rather larger than this, for they contained 15,000 cubic feet, but the brick buildings were continued for some time; and those erected at Chester and Birmingham exposed to the open air were much disapproved of. The expense thus entailed upon the Company may therefore be imagined; but this was only an item; retorts were £20 per ton, street mains £14 per ton, and no service-pipes were to be bought at all. The great cost of making sheet-iron or copper tubes was very serious. Many manufacturers were applied to to make pipes, but without success; they would not expend money for machinery to construct anything connected with such a "foolish, unlucky thing" as Gas! At length however Mr. James Russell, who at that time was in the employ of Mr. Aaron Manby, of the Horsley Iron Works, and to whom it is believed the original idea is due of substituting machinery for manual labour in the welding of gas tubes, undertook the matter. These services were called gun-barrel pipes, from the circumstance of gun-barrels having been used for services as before remarked.

Stop-cocks and burners were equally difficult to get made at anything like a price which would permit them to be used generally; but these were undertaken by Messrs. Dixon and Vardy, of Wolverhampton, and in the course of a little time produced at a moderate cost.

Again, the street mains were found to be too small; two of six inches diameter only leading from the works: these had to be taken up and replaced by larger ones, which in their turn had to be enlarged.

At this time the gas-meter was not invented, and the consumers burnt as much gas as they chose, at a rent calculated upon the datum of 15*s.* per thousand cubic feet; nor were street inspectors employed to check the burners.

Lastly, the quantity of gas produced from a chaldron of coal was only 10,000 cubic feet, and the fuel expended to heat the retorts amounted to between 50 and 60 per cent. of the coke produced.

The gas-meter, together with the governor, was invented and patented by Mr. Clegg in 1815. The first meter consisted of two large bladders filled alternately with gas, and contained in tin cases weighted to a certain pressure, the openings between them and the burners being alternately opened and closed by quicksilver seal valves; owing to the action of the various condensed impurities upon the bladders, they soon gave way. Leather and different kinds of membrane, coated with varnish or gold-leaf, were then tried, but they also became stiffened and useless in a few months. Recourse was then had to two small metallic vessels working in the same manner as the bladders, but the lights were unsteady, and the intervention of a governor was necessary, which made the machine expensive, and the space occupied by it inconveniently great. The dry meter was then discarded, and the water meter contrived, which is too well known to require a description here; it however underwent several changes before it was rendered completely efficient, and Mr. Clegg was indebted for an improvement to his assistant, the late Mr. James Malam, who contrived the bent inlet pipe in the place of the hollow axis which previously admitted the gas. The late Mr. Samuel Crosley, who became the manufacturer, also improved its commercial form. About the year 1817 the meter began to be used to a considerable extent; and it is to the introduction of this simple instrument that the great success of gas-lighting must be mainly attributed. New gas companies were formed, new works erected, manufacturers entered into competition to produce the several parts of the apparatus at less and less cost, and the manufacture became a distinct branch of trade. As an example of the new impetus, it may be stated that in 1817 the coal used in the production of gas in London was only about 5000 chaldrons; in 1823 the number of chaldrons was 33,158 by the three companies, viz., the Chartered, the City, and the Imperial. The length of street mains in 1817 was 20 miles; in 1823 there were 215 miles, the price of gas being 10*s*. per thousand cubic feet. About this year, also, the sizes of the gas-holders were increased to a capacity of 40,000 cubic feet, and the per-centage of fuel used for carbonization was reduced to 35 per cent. About the year 1824 the gas-meter began to be very generally adopted; and this, giving to the companies an approximate knowledge of the gas produced and sold by them, added a still greater impetus to the already fast advancing trade; and the following

brief statistical account of the state of the gas operations in 1851 will best show the results.

Gas-holders, which at first were timidly made to contain 15,000 cubic feet, now are constructed to hold 750,000 cubic feet, being fifty times the first-named capacity. In 1824 the number of gas companies in London was three; in 1851 there were fourteen, and nineteen stations; the total number now in Great Britain being about eight hundred. In 1824 there were 50,000 tons of coal used in the production of gas in London; in 1851 there were 500,000 tons used in one establishment. In 1824 there were 250 miles of main pipe in the streets of London; in 1851 there were 2000 miles; and the initial mains, which in 1824 did not exceed 12 inches in diameter, are now in several instances 26 inches.

With increased consumption came, as a natural consequence, decrease of the cost of production.

In 1817	the price of	gas was	15*s*. 0*d*.	per thousand	cubic feet.
„ 1824	„	„	10*s*. 0*d*.	„	„
„ 1830	„	„	9*s*. 0*d*.	„	„
„ 1840	„	„	7*s*. 0*d*.	„	„
„ 1851	„	„	4*s*. 6*d*.	„	„

With all the immense improvements in the commercial state of gas companies, it will appear very strange that until 1849 the process of manufacture should have remained almost the same as that practised forty years ago—the only advance being, that while at first 8000 cubic feet was the utmost that could be obtained from one ton of coal, 10,000 cubic feet are now abstracted, having the same illuminating power. Several attempts have indeed been made, other hydro-carbonaceous substances have been proposed from which to obtain the gas, but they have entirely failed, either practically or commercially. Water gas, as it was termed, obtained for a short period a degree of favour, but it also failed in realizing the promised results.

In 1849, however, Mr. White, of Manchester, introduced what he termed his hydro-carbon gas; and from the results of experiments just made on a working scale, it may be fairly predicted that the process will be a successful one.

A great number of schemes for improvements in gas apparatus have been patented within the last twenty-three years; but all, except a few for improvements in construction, are of little importance. I have noticed the most valuable in this work.

CHEMISTRY, AS APPLIED TO THE MANUFACTURE OF COAL-GAS.

THE processes used in the manufacture of gas for illuminating and heating purposes, are in their nature essentially chemical; a certain amount of chemical knowledge is therefore absolutely requisite for the carrying on of the various operations of such manufacture in the most satisfactory and economical manner. This amount of knowledge may however be attained without a thorough acquaintance with the whole of the laws and doctrines of chemical science; and it is therefore not my intention here to write a treatise on chemistry,—a sufficient number of excellent ones already exist,—but simply to bring prominently forward the properties and reactions of such substances as are of present interest and importance to the gas manufacturer, or which are likely to lead to the future improvement and perfection of this important branch of industry.

Chemical Affinity.—When a piece of phosphorus is exposed to the air it emits a white smoke which is luminous in the dark; the phosphorus gradually disappears, and if the experiment be conducted in a dry glass vessel the latter will gradually become coated with a white powder, which on further examination will be found to be a compound of phosphorus and oxygen. Here, then, the phosphorus has combined with one of the constituents of the air, oxygen, to form a white pulverulent compound called phosphorous acid, and the force or tendency which thus determined this union is termed the *chemical force* or *chemical affinity*. It is the study of the phenomena produced by this force, and the laws by which its operations are regulated, that constitute the science of chemistry.

The exertion of chemical affinity is generally rendered evident by very striking phenomena. It usually produces an entire change of properties in the bodies which are made to unite by its agency: thus in the instance just mentioned, phosphorus, a neutral wax-like highly combustible solid, insoluble in water; and oxygen, a colourless and invisible gas, by their chemical union generate phosphorous acid, a white solid, soluble in water, intensely acid and incombustible; in short, a body in which the attributes of its component elements are entirely lost.

The exertion of chemical affinity is also usually attended by an alteration of temperature, and sometimes by the production of light and electricity. It is also distinguished from all other species of combination by the remarkable circumstance that when bodies unite chemically they do so in certain fixed and invariable proportions. The elements of a compound body are always united in exactly the same ratio, whether the substance has been formed ages ago by the operations of nature, or but recently in the vessels of the chemist. Thus the elements of water —oxygen and hydrogen—are always united in the ratio by weight of eight parts of the former element to one part of the latter; or by volume, of one volume of oxygen to two volumes of hydrogen. This combining weight peculiar to each element is termed the *combining proportion* or *atomic weight* of that element.

Two elements may unite in several proportions, but it is remarkable that these proportions bear a very simple relation to each other, whilst each variation produces a distinct compound which frequently bears no resemblance to the others. Thus, as we have already stated, eight parts of oxygen and one part of hydrogen form water; but one part of hydrogen can also unite with sixteen parts of oxygen, producing a liquid having very different properties, being highly corrosive, blistering the skin when applied to it, and exhibiting very violent reactions in contact with certain substances. Again, fourteen parts of nitrogen unite with eight parts of oxygen, and the same weight of nitrogen also combines with double, treble, four times, and even five times this amount of oxygen, producing in each case a separate compound, distinguished from the rest by peculiar properties.

In the case of gases and bodies which are capable of being converted into the gaseous or vaporous condition, the combining proportions by volume are still more simple. Thus, one volume of one gas or vapour unites with one, two, or three of another, or in the proportion of two to three, etc.: for instance, one volume of oxygen unites with one volume of hydrogen to form the corrosive liquid above mentioned, and one volume of oxygen combines with two volumes of hydrogen to form water.

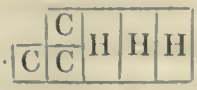
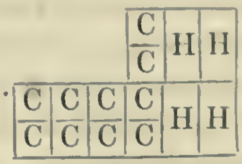
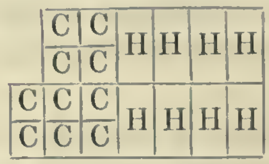
We are however unable to convert many of the elements into vapour, and we cannot therefore experimentally ascertain their combining volume. Under these circumstances we have to assume a combining volume, and in doing so are guided by the analogy between the non-volatile element and other volatile ones whose combining volumes we have actually ascertained. Carbon, for instance, has not hitherto been volatilized, but we assume that six parts, or one combining proportion, occupy the same space in the gaseous condition as eight parts, or one

combining proportion, of oxygen; we therefore say that carbonic oxide gas, which consists of six parts or one atom of carbon combined with eight parts or one atom of oxygen, is composed of one volume of *carbon vapour* and one volume of oxygen; and that carbonic acid, which contains one atom of carbon and two atoms of oxygen, consists of one volume of carbon vapour united with two volumes of oxygen.

When two gases or vapours unite *chemically*, a contraction of volume usually ensues, but the resulting gaseous volume of the compound always bears a very simple relation to the volume of the two gases before combination. Thus, when one volume of oxygen unites with two volumes of hydrogen, the resulting watery vapour occupies two volumes: a contraction or diminution of volume from three to two has therefore occurred in this instance. Again, two volumes of carbon vapour unite with four volumes of hydrogen to form olefiant gas, which occupies two volumes, or exactly one-half of the space occupied by the hydrogen before combination.

The following diagram represents the composition by volume of all the compound gases and vapours which are of importance to the gas manufacturer. The column headed "before combination" represents the gaseous volume of the elements composing such gas or vapour before their chemical union; and a comparison of this column with that headed "after combination" shows the amount of contraction which has occurred at the moment of combination. The letters O, H, and C are employed to represent respectively oxygen, hydrogen, and carbon.

	VOLUME BEFORE COMBINATION.	VOLUME AFTER COMBINATION.
Vapour of Water	O | H	H O
Carbonic Oxide	O | C	C O
Carbonic Acid	O, O | C	C O_2
Light Carburetted Hydrogen	C | H | H	C H_2
Olefiant Gas	C, C | H | H	C_2 H_2

	VOLUME BEFORE COMBINATION.	VOLUME AFTER COMBINATION.
Propylene....................		.... $C_3\ H_3$
Butyrene		.... $C_4\ H_4$
Naphthaline Vapour		.... $C_{10}\ H_4$
Turpentine Vapour		.... $C_{10}\ H_8$

Influence of other forces upon Chemical Affinity.—Chemical affinity is greatly modified and controlled by the forces of heat, light, electricity, and cohesion. The modifications effected by heat and cohesion are alone of interest to the gas manufacturer. It is by the mutual action of these two antagonistic forces, which have been appropriately termed the attractive and repulsive forces, that the state of aggregation of all matter is determined; a preponderance of the cohesive force producing the solid condition of matter; the equilibrium of the two forces, the liquid; and an excess of the repulsive force, the gaseous or vaporous condition. Now as chemical affinity acts only at insensible distances—in other words, as each atom of the combining substances must be in intimate contact before the chemical force can be exerted between them—it will be obvious that the physical state of a body must considerably modify the action of chemical affinity. Between solids, for instance, where the atoms are congregated together into a hard mass, affinity can rarely be exerted, since the mobility of the atoms is prevented, and the points of contact between the two substances are so few. In gases, the repulsion which exists between the atoms, preventing their contact, is also generally fatal to combination. The liquid state is therefore the most favourable to chemical union: the ultimate particles of a liquid are sufficiently mobile to allow it to mix intimately with the substance with which we wish it to combine, while they are sufficiently

approximated to be within the sphere of chemical attraction. The old axiom of the alchemists still obtains, "Corpora non agunt nisi sint soluta."

The effects of heat in modifying chemical affinity vary according to the nature of the substances which come under its influence; usually it appears to increase the intensity of the chemical force and thus favours combination, unless its repulsive action drives the particles of the combining bodies to a greater distance from each other than that at which chemical attraction can exert its influence. Thus the affinity of carbon for oxygen is so small at the ordinary temperature, that these elements may remain in contact for ages without evincing the slightest tendency to combine; but if the temperature be raised to dull redness, combination begins to take place, and at still more elevated temperatures the affinity between them becomes so intense, that carbon can, under these circumstances, withdraw oxygen from almost every other compound containing this element.

The affinity of carbon for hydrogen appears to be affected by heat in a manner directly opposite. With one solitary exception, which is not of the slightest importance to the gas manufacturer, we know of no artificial process by which a union of these elements can be produced. When brought together they do not exhibit the slightest tendency to combine at any temperature to which we can subject them. It is only by the agency of the vital force exerted in the tissues of animals and vegetables, that the union of these elements can be effected. We are therefore indebted to animal and vegetable organisms for every particle of hydro-carbon that has ever existed.

When however any compound of these two elements, formed as above described, is submitted to an elevated temperature, the uniting force always appears to decrease as the temperature increases. Thus the more condensed hydro-carbons, as olefiant gas, naphthaline, etc., are decomposed at a red heat, depositing a portion of their carbon, and being converted into light carburetted hydrogen, which last, at a somewhat higher temperature, is entirely resolved into its elements, carbon and hydrogen.

These two facts,—the necessity of the vital force for the production of hydro-carbons, and the diminution of the affinity between carbon and hydrogen by increased heat,—are of the highest importance to the gas manufacturer; a knowledge of them would have entirely prevented the expenditure of so much trouble and capital in those numerous futile contrivances for increasing the illuminating power of gas, or, in other words, increasing the quantity of hydro-carbon by passing it through red-hot retorts, etc., filled with coke, plumbago, and other carbonaceous

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materials. It is utterly impossible that any union of carbon with hydrogen can take place under such circumstances.

Of the substances contained in Coal-Gas, or which are concerned in its generation and combustion.—The substances which enter into the composition of Coal-Gas, or are concerned in its generation and combustion, are the following:—

Oxygen.	Light Carburetted Hydrogen.
Hydrogen.	Olefiant Gas.
Nitrogen.	Hydrocarbons.
Carbon.	Sulphur.
Carbonic Oxide.	Bisulphuret of Carbon.
Carbonic Acid.	Sulphuretted Hydrogen.
Water.	Cyanogen.
Ammonia.	

I will now briefly describe the nature and properties of these elements and compounds.

Oxygen.—This element exists in the free state as a colourless, invisible, and inodorous gas, very sparingly soluble in water, and which has hitherto resisted all attempts to liquefy it by cold or pressure. In this condition it is evolved from the leaves of plants under the influence of light, and constitutes about one-fifth of the bulk of our atmosphere. By far the largest amount of oxygen however exists in combination with other elements; thus, eight out of every nine tons of water are pure oxygen, and it forms at least one-third of the total weight of the mineral crust of our globe. It is therefore the most abundant of all elements. Oxygen gas is heavier than atmospheric air; 100 cubic inches at 60° Fahr. and 30 inches barometric pressure weighing 34·193 grains, whilst 100 cubic inches of the latter weigh only 31·0117 grains. Since atmospheric air is taken as unity when comparing the density of gases, the specific gravity of oxygen is 1·1026. It eminently supports combustion, all combustible bodies when introduced into it burning much more vividly than in common air; indeed it is to the presence of this gas that the property of supporting combustion, which common air possesses, is owing.

The union of oxygen with other elements is always attended by an elevation of temperature. When the union is very slow, as in the rusting of iron, the heat developed cannot be appreciated; but when combination is rapidly effected, it is attended with the phenomenon of light as well as heat, as in ordinary combustion.

It was formerly thought that the heat developed during combustion was always

proportionate to the quantity of oxygen consumed; but recent experiments have not confirmed this opinion, although in the case of the combustion of carbon and hydrogen it is not far from the truth. We are indebted to Berthier for an expeditious process for ascertaining the value of a combustible founded on this fact. He mixes the substance to be tested with several times its weight of oxide of lead (litharge), and exposes the mixture in a crucible to a heat sufficient to fuse it. Oxide of lead is composed of oxygen and lead, in the proportion of 8 parts by weight of the former to 104 of the latter. At a red heat the combustible matter seizes upon the oxygen and reduces the lead to a metallic state. This melts and collects in the form of a button at the bottom of the crucible. As we have shown that the proportions in which bodies unite are always uniform, it is evident that for every portion of oxygen consumed a certain portion of lead will be reduced, so that the effective combustible matter in the compound examined will be in due proportion to the weight of the button of lead. This process is not entirely free from objections, but sufficiently so for many practical purposes.

Oxygen is usually a constituent of Coal-Gas as supplied to the consumer, owing to unavoidable leakages and the introduction of atmospheric air into the retorts and purifiers when these vessels are opened. Its presence is highly injurious to the illuminating power of the gas, as will be presently noticed; and as there is no practicable means of removing it from the gas, its introduction ought to be guarded against as much as possible.

Hydrogen.—This element is, like oxygen, in a free state a colourless, invisible, and inodorous gas, scarcely soluble in water. It is very rarely met with in nature uncombined; but free hydrogen has lately been detected in the gases which issue from volcanoes. In combination it constitutes one-ninth of the total weight of the waters of our globe, and also enters largely into the composition of animals and vegetables, and substances derived from them, as oils, peat, coal, and bitumen.

Hydrogen gas is generated in abundance nearly pure when steam is passed over iron, zinc, and several other metals in a fine state of division at a full red heat. Mixed with carbonic oxide and carbonic acid gases, it is also generated in large quantity when steam is passed over charcoal, coke, or other carbonaceous substances at a red heat. In all these cases the watery vapour is decomposed, its hydrogen being liberated, whilst its oxygen unites with the metal or carbon, forming in the first case a solid non-volatile oxide, which encrusts the pure metal and soon stops further action; in the second case a gaseous oxide of carbon is generated and passes off along with the hydrogen, thus leaving the carbon freely

exposed to the further action of the watery vapour. That portion of the steam which is converted into hydrogen and carbonic oxide yields its own volume of each of these gases; and that portion which forms hydrogen and carbonic acid affords its own volume of hydrogen and half its own volume of carbonic acid. The amount of watery vapour which undergoes the latter decomposition decreases as the temperature at which the operation is conducted increases. At a white heat scarcely a trace of carbonic acid is produced.

Hydrogen is the lightest of all known bodies, its specific gravity being only ·0691; 100 cubic inches at 60° Fahr. and 30 inches barometric pressure weigh only 2·1371 grains. It has a powerful affinity for oxygen, but developes scarcely any light during combustion: when however solid substances, such as lime, magnesia, or platinum, are held in the flame of hydrogen, considerable light is emitted. Burnt in air or oxygen gas it is entirely converted into watery vapour, which condenses upon cold surfaces held above the flame.

One cubic foot of hydrogen at 60° Fahr. and 30 inches bar. pressure, consumes half a cubic foot of oxygen, generates one cubic foot of watery vapour, and affords heat capable of raising the temperature of 1 lb. 13 oz. of water, from 32° Fahr. to 212° Fahr.; or that of a room containing 2500 cubic feet of air from 60° Fahr. to 66·4° Fahr.

Water.—We have already stated that water is composed of two volumes of hydrogen and one volume of oxygen, or one part by weight of hydrogen and eight parts of oxygen. Oxygen and hydrogen, though mixed in the proper proportions for combining, do not unite until the temperature of a portion of the mixture has been raised to redness; they then unite with a loud explosion. When brought together gradually and inflamed, as when a jet of oxygen is admitted into a jar of hydrogen, or *vice versâ*, they burn quietly with a non-luminous but intensely hot flame, and produce pure water.

The general properties of water are too well known to require description. It is always produced by the decomposition of coal by heat. This arises from two causes: the presence of hygrometric water in the coals, and likewise from its elements forming a part of their composition. The former portion is the first product which passes from the retorts; the second only comes over when the actual decomposition of the coal has commenced. This water is condensed and carried into the tar-well, where it holds in solution many of the more soluble products of the distillation. Beside its well-known solvent action upon solids, water possesses the property of absorbing or dissolving gases; and a knowledge

of its relative solvent action upon the various gases is of great importance to the gas manufacturer.

The following table exhibits the number of volumes of various gases which 100 volumes of water at 60° Fahr. and 30 inches barometric pressure can absorb :—

Ammonia	7800 volumes.
Sulphurous Acid	3300 ,,
Sulphuretted Hydrogen	253 ,,
Carbonic Acid	100 ,,
Olefiant Gas	12·5 ,,
Illuminating Hydro-carbons	Not determined, but probably more soluble than olefiant gas.
Oxygen	3·7 volumes.
Carbonic Oxide	1·56 ,,
Nitrogen	1·56 ,,
Hydrogen	1·56 ,,
Light Carburetted Hydrogen	1·60 ,,

When water has been saturated with one gas and is exposed to the influence of a second, it usually allows a portion of the first to escape whilst it absorbs an equivalent quantity of the second. In this way a small portion of a difficultly soluble gas can expel a large volume of an easily soluble one, a familiar instance of which we have in the case of a glass of champagne which has ceased to sparkle, but which is again brought into a state of brisk effervescence by a smart blow upon the mouth of the glass with the concave palm of the hand. Under the pressure thus produced, the wine absorbs a small quantity of atmospheric air, which then expels a considerable amount of the more soluble carbonic acid.

Nitrogen.—This is another of the gaseous elements. It exists in a free state in the atmosphere, and enters into the composition of a large number of animal and vegetable substances. All descriptions of coal contain small quantities of this element. When nitrogen is eliminated from combination in contact with oxygen, it usually takes the form of nitrous or nitric acid; whilst in contact with an excess of hydrogen it generates ammonia. It is in this latter form that it is eliminated from coal in the process of gas-generation.

Nitrogen is a colourless, inodorous, and tasteless gas, of specific gravity 0·976. It is incombustible under ordinary circumstances, and instantaneously extinguishes burning bodies. Under certain conditions however nitrogen does undergo combustion, as when it is exposed to a very intense heat in the presence of oxygen. This occurs, for instance, when a small quantity of nitrogen is added to a mixture

of hydrogen, with a somewhat larger proportion of oxygen than is requisite to form water, and the mixture then ignited: a loud explosion takes place, and a considerable quantity of nitric acid is formed, owing to combustion of the nitrogen, or in other words, its union with oxygen gas. This formation of nitric acid no doubt occurs also to a limited extent during the burning of coal-gas; and as the temperature required to form nitric acid is very high, the greater the volume of gas consumed from one burner in a given time, the greater will be the relative quantity of nitric acid produced. The formation of such a corrosive material as nitric acid under these circumstances shows the importance of preventing the admixture of the products of the combustion of coal-gas with the atmosphere of the apartments in which it is consumed.

The presence of free nitrogen in coal-gas is probably due entirely to the admission of atmospheric air, and not to the elimination of the nitrogen contained in the coal; for this latter nitrogen appears to be evolved only in combination with hydrogen as ammonia. As nitrogen is incombustible, it is not only a useless ingredient in coal-gas, but owing to its abstracting heat from the flame of such gas it causes a diminution of light, and is thus decidedly injurious. The admixture of this element ought therefore to be avoided as much as possible.

Ammonia.—Ammonia is formed during the distillation of coal, and of all organic substances containing nitrogen. In such distillation the nitrogen unites with hydrogen, in the proportion of fourteen to three, the formula being $N\,H_3$, and ammonia is the result. It is a colourless gas, specific gravity ·5898, very pungent, acting strongly on the nose and eyes when respired. It dissolves in a very small portion of water, one volume of this liquid taking up about 780 volumes of the gas, and forming a liquid possessed of similar properties, and sold in the shops under the name of *spirits of hartshorn.* Ammonia is strongly alkaline, uniting readily with all the acids, and forming salts which sublime at a comparatively low temperature. It also unites with sulphuretted hydrogen, producing a highly offensive volatile substance. Gaseous ammonia unmixed with other gases is incombustible, but when present in coal-gas it burns with the latter, and is converted principally into nitric acid.

The greater part of the ammonia produced in the manufacture of gas is found in the liquor which floats on the surface of the bituminous substances in the tar-well; it is collected and sold to the manufacturers of ammoniacal salts, or otherwise disposed of. In the account of the secondary products will be found a description of the best methods pursued by these manufacturers.

Carbon.—This element is well known under the form of diamond, charcoal, lamp-black, and coke, all of which substances are carbon mixed with small and variable quantities of foreign matters. A knowledge of the chemical properties of carbon is of great importance to the gas-manufacturer, as it is the basis of the illuminating gases.

Carbon, as we have already mentioned, does not combine with oxygen at ordinary temperatures, but does so with great energy on the application of a strong heat, emitting at the same time intense light, which increases in brilliancy as the temperature rises; it is not however the particles of carbon which are actually undergoing combustion that emit this light, but those which are heated to incandescence, or are suspended for an instant within the flame before they come in contact with the atmospheric oxygen. This important fact will be again referred to.

Carbon exhibits no tendency to unite with hydrogen at any temperature unless these elements are under the influence of the vital force, as in the bodies of animals and the tissues of plants: under this influence however they unite in almost innumerable proportions, forming a most extensive and highly important series of bodies, known under the name of hydrocarbons.

Carbon unites with oxygen in two proportions, forming carbonic oxide and carbonic acid gases.

Carbonic Oxide.—This is the lowest state of oxidation of carbon; it contains one equivalent or six parts of carbon, and one equivalent or eight parts of oxygen. This gas is formed when carbon is consumed in a limited quantity of air or oxygen, and is also generated, as stated above, when steam is passed over ignited coke or charcoal, or when coal-tar and steam meet in a red-hot vessel. It is always a constituent of coal-gas.

Carbonic oxide is a colourless and inodorous gas, rather lighter than atmospheric air, and having exactly the specific gravity of olefiant gas, ·9727; it is very sparingly soluble in water, but is very soluble in an ammoniacal solution of subchloride of copper. Carbonic oxide is inflammable, burning with a beautiful blue flame almost devoid of light: the product of its combustion is carbonic acid. One cubic foot, at 60° Fahr. and 30 inches barometric pressure, consumes during combustion half a cubic foot of oxygen, generates one cubic foot of carbonic acid, and yields heat capable of raising 1 lb. 14 oz. of water from 32° to 212° Fahr., or causing a rise of temperature from 60° to 66·6° Fahr. in a room containing 2500 cubic feet of air.

Carbonic Acid.—This gas is always generated when carbon is burnt in an excess of air or oxygen; it is formed during fermentation, putrefaction, and decay, and in small quantity during the earlier stages of the decomposition of coal in red-hot retorts; it is also a product of the decomposition of water by carbon at a red heat.

Carbonic acid differs strikingly from carbonic oxide in its properties, though it only differs in constitution by containing double the quantity of oxygen; the latter containing six parts of carbon and eight parts of oxygen, whilst the former contains six parts of carbon and sixteen parts of oxygen. Carbonic acid is pungent, acidulous, and soluble in an equal bulk of water, to which it communicates that briskness which we so much admire in soda-water; it is considerably heavier than atmospheric air, its specific gravity being 1·524. This gas is uninflammable, and cannot support combustion or animal life. Its acid properties are not strongly developed, but it unites readily with alkaline bases, forming carbonates: it is upon this property that the removal of carbonic acid from coal-gas depends. On passing coal-gas containing this acid through slaked lime in fine powder, or through milk of lime, nearly the whole of the carbonic acid disappears, having united with the lime; if however the gas contains a large quantity of carbonic acid (upwards of 3 per cent.) this method will not suffice for its removal, and the following must be substituted:—Dissolve 1 cwt. of soda in 120 gallons of water, and add 70 to 80 lbs. of unslaked lime (larger quantities in like proportion); stir the mixture well until the lime is perfectly reduced to a pulp, and then transfer it to the wet-lime purifier, in which it must be occasionally well agitated. This mixture will be effective for the removal of carbonic acid until a sample of the clear liquor effervesces strongly on the addition of a few drops of muriatic acid: when this is the case the mixture must be run off from the purifier and allowed to settle in a suitable tank; the carbonate of lime (chalk) will subside, leaving the original clear solution of soda floating above; this must be pumped up into the lime-vat, and treated with lime as before. It will be perceived that in this process the lime alone is wasted, the soda being used over and over again, and acting only as a carrier of carbonic acid from the gas to the lime. By this method, every trace of carbonic acid is removed, and the quality of the gas in no degree impaired.

Quick-lime, slaked in such a manner as to be neither dust-dry nor very perceptibly moist, is also said to be perfectly effective for the absorption of high percentages of carbonic acid, a layer one inch in thickness not allowing a trace of the acid gas to pass through it.

The presence of a small per-centage of carbonic acid in coal-gas is only to be deprecated on account of the slight loss of light which it occasions; the addition which it makes to the carbonic acid produced during combustion being too minute to be of any importance.

Light Carburetted Hydrogen.—This compound, which is also known to chemists under the names of *marsh gas* and *hydride of methyl,* is always a constituent of coal-gas; it is also a natural product of the slow decomposition of coal, and of putrefaction in general: thus it occurs in enormous quantities in the coal strata, and bubbles up from stagnant pools and ditches which contain putrefying organic remains. As thus generated, it is mixed with small quantities of carbonic acid and nitrogen; it can however be artificially prepared perfectly pure, but the processes need not be described here.

Light carburetted hydrogen when pure is colourless, tasteless, and inodorous; it is neutral to test-papers, and nearly insoluble in water; its specific gravity is ·5594, and 100 cubic inches at 60° Fahr. and 30 inches barometric pressure weigh 17·4166 grains. It does not support combustion or respiration, but is inflammable, burning with a blue or slightly yellow flame, yielding scarcely any light; mixed with a due proportion of atmospheric air or oxygen and ignited, it explodes with great violence: the products of its combustion are water and carbonic acid. One cubic foot of light carburetted hydrogen at 60° Fahr. and 30 inches barometric pressure consumes two cubic feet of oxygen and generates one cubic foot of carbonic acid; during combustion it yields heat capable of raising the tempera- of 5 lb. 14 oz. of water from 32° to 212°, or that of a room containing 2500 cubic feet from 60° to 80·8°.

When light carburetted hydrogen is exposed to a white heat it is slowly decomposed, depositing carbon and yielding twice its volume of hydrogen.

Olefiant Gas.—This gas is rarely met with in nature, but as it is generated in great abundance when coals or other bituminous matters are exposed to high temperatures, it might be expected to occur when any coal-bearing strata are exposed to volcanic heat, and has in fact been occasionally met with as a natural product under these circumstances. Olefiant gas nearly pure can be prepared artificially by heating in a suitable glass retort a mixture of one part by weight of alcohol and five or six parts of concentrated sulphuric acid; the gas should be passed through a solution of caustic soda, to remove the sulphurous acid and carbonic acid with which it is generally contaminated.

Olefiant gas is colourless, and possesses a peculiar and somewhat unpleasant

odour; its density is ·9784; 100 cubic inches at 60° Fahr. and 30 inches barometric pressure weigh 30·3418 grains. It consists of two volumes of carbon vapour and four volumes of hydrogen, the six volumes being condensed to two; it therefore contains in a given bulk exactly twice as much carbon as light carburetted hydrogen. Olefiant gas is inflammable, but does not support combustion: when inflamed as it issues from a jet into the atmosphere it burns with a large white flame, emitting a very brilliant light without smoke; during its combustion it consumes three times its volume of oxygen and generates twice its volume of carbonic acid. Passed through a red-hot tube, or otherwise exposed to a full red heat, it is rapidly decomposed, carbon being deposited, and hydrogen and probably light carburetted hydrogen produced: by being thus treated, its illuminating power is therefore entirely destroyed. Olefiant gas is probably always present in coal-gas, and contributes greatly, though not exclusively, to its illuminating power.

Hydrocarbons.—This name has been applied to a very large number of compounds formed principally by the destructive distillation of organic bodies, and composed of carbon and hydrogen united together in various proportions. Some of these compounds are gaseous, others liquid, and several solid: their history is at present very imperfect, their composition and properties having been very little examined. We will notice only the most interesting of this exceedingly numerous class of bodies.

Gaseous Hydrocarbons.—The hydrocarbons which exist at the ordinary temperature and pressure of the atmosphere in a gaseous form are of the utmost importance to the gas-manufacturer; indeed the manufacture of gas for illuminating purposes has for its principal object the production of the largest amount of gaseous hydrocarbons from a given weight of material. The only gaseous hydrocarbons of known composition which have been proved to be present in coal-gas are the two just described under the names of light carburetted hydrogen and olefiant gas; there are however strong reasons for believing that, in addition to a host of unknown ones, at least two others exist in coal-gas, whose composition and properties have been investigated—these are propylene and butylene. The first is produced artificially by passing the vapour of fousel oil through a red-hot tube; and the second, which is present in oil-gas, is generated during the electric decomposition of valerate of potash. Both these gases are colourless, possess a slight ethereal odour, and burn with a brilliant white flame, having an illuminating power much

greater than that of olefiant gas; they are rapidly decomposed when subjected to a red heat. Propylene consists of three volumes of carbon vapour and six volumes of hydrogen, the nine volumes being condensed to two: it hence contains 50 per cent. more carbon in a given volume than olefiant gas. Its specific gravity is 1·4511. Butylene consists of four volumes of carbon vapour and eight volumes of hydrogen, the twelve volumes being condensed to two; it therefore contains double the amount of carbon present in an equal volume of olefiant gas. Its specific gravity is 1·9348.

As the illuminating power of these gases is directly proportionate to the amount of carbon contained in a given volume, the illuminating values of olefiant gas, propylene, and butylene must be as 1 : 1·5 : 2.

Liquid Hydrocarbons.—These make up the great bulk of the tar produced in the process of gas-making, and compose the coal naphtha and coal oil obtained by the distillation of tar. The more volatile portion of them diffuse their vapour into the gas itself, and thus contribute in no inconsiderable degree to augment its illuminating power: this they do by reason of the large quantity of carbon which a given volume of their vapour contains, and which may be seen by reference to the diagram at page 25. The number of these hydrocarbons is very great, but a few only have been investigated: we will only direct attention to one or two, which promise to become of commercial importance.

Benzole.—This remarkable hydrocarbon is contained in the portion of crude coal-tar naphtha which distils over between the temperatures of 176° and 194°*. Benzole is a colourless and transparent liquid, of specific gravity 0·85, having a pleasant ethereal smell and boiling at 177°; at 32° it solidifies to a white crystalline mass like camphor. It is extremely inflammable, its vapour readily taking fire on the approach of flame; in fact so much vapour is formed at ordinary temperatures that a current of hydrogen, or even of atmospheric air passed through it and afterwards ignited at a jet, burns with a white flame highly luminous. Benzole acts as a powerful solvent for many substances: thus it readily dissolves many resins, mastic, camphor, wax, fatty and essential oils, caoutchouc, and gutta percha; it dissolves shell-lac sparingly, but mixes in equal bulks with a saturated solution of lac in wood-spirit or alcohol. Treated with nitric acid benzole is converted into nitro-benzole, a liquid possessing a very agreeable odour, similar to that

* For a minute account of the method of extracting Benzole, see a pamphlet published on the subject by Mr. Mansfield.

of oil of bitter almonds, and which is now very extensively used as a substitute for that essential oil in perfumery.

Carbolic Acid.—This singular compound is contained in that portion of coal-oil which boils between 300° and 400°. If this portion of oil be agitated with twice its volume of soda lye, the aqueous solution on the addition of an acid yields carbolic acid as a heavy oil; it is purified by being rectified with a small quantity of solid potash. Carbolic acid has the appearance of a colourless oily liquid, of a burning taste and a penetrating smell like creosote; its specific gravity is about 1·062. It is of interest from its close chemical relation to indigo, and from its powerful antiseptic and preservative properties, which are quite equal to those of creosote, for which liquid it could probably be in most cases substituted.

Eupion.—This is a liquid prepared from cannel coal tar by repeated treatment with concentrated oil of vitriol and subsequent rectification from soda lye; it possesses a pleasant fruity smell, and might probably be used with advantage as a solvent for gums and resins, and as a substitute for chloroform.

Solid Hydrocarbons.—The principal solid hydrocarbons derived from coal-tar are paraffine, naphthaline, paranaphthaline, chrysene, pyrene, and pittacal; these are all dissolved in the liquid constituents of the tar, and become separated during the subsequent distillation.

Paraffine is a white solid substance resembling wax. It melts at 110°, and distils without decomposition at a high temperature; its specific gravity is 0·870. When made into candles it burns with a clear white light free from smoke, and fully equal to the best white wax. Dissolved in the less volatile portions of the Boghead coal-oil, it forms the so-called Paraffine oil, which possesses lubricating properties in no wise inferior to these of sperm oil, for which it is now being extensively substituted. Paraffine is contained only in considerable quantity in the tar from Boghead cannel; the latter portions of the heavy oil procured by the distillation of this tar are semi-solid, owing to the large quantity of paraffine crystals which they contain: by straining through a canvas filter and pressure, the impure paraffine is obtained; it is further purified by treatment with concentrated sulphuric acid.

Naphthaline, Paranaphthaline, Chrysene, and Pyrene, are white crystalline bodies much resembling each other in appearance, but differing in volatility and chemical composition. Naphthaline, which is the most volatile, seems to be always present in coal-gas, which owes its disagreeable odour principally to this substance. When

the gas charged with naphthaline vapour is allowed to leave the holder at a temperature higher than that of the mains through which it subsequently flows, a portion of the naphthaline is deposited as the gas cools, and the constant additions of this deposit finally diminish so much the bore of the pipes as to be the cause of great inconvenience. This would probably be avoided by passing the gas over a large surface of coal-oil previous to its transmission into the mains; the oil would dissolve so much of the naphthaline as to prevent any subsequent deposition.

Naphthaline has not yet received any important technological applications, but by being submitted to certain chemical processes it yields chloronaphthalic acid, a compound possessing nearly the same composition and properties as *alizarine*, the most valuable colouring principle of the madder-root; there is therefore good reason to hope that we shall soon be able to convert the vast accumulations of naphthaline about our gas-works into the most valuable of dye-stuffs.

Pittacal.—This remarkable substance was found by Reichenbach in the heaviest portions of the oil of tar: the methods for its separation and purification are not yet known; it is however said to be a solid of a very fine deep blue colour like indigo, its polished surface having a golden lustre; it can be fixed on cloth, and would form a most valuable dye-stuff. There appears therefore every probability that the nauseous, unsightly, and almost useless coal-tar will, in addition to the odoriferous eupion and nitro-benzole, soon be made to yield large quantities of those magnificent colouring matters, alizarine and indigo.

Bisulphuret of Carbon.—This compound is formed whenever sulphur and carbonaceous matter are brought together at a bright red heat; and therefore, owing to the presence of sulphur in all varieties of coal, its vapour is generally and probably always present in coal gas. Bisulphuret of carbon is a colourless liquid, of a most insupportable odour resembling garlic; it is very volatile, boiling at 108°. It does not mix with water, but dissolves in alcohol and ether; it is also very soluble in a solution of caustic soda or potash, and in methylic, ethylic, or amylic alcohol. It is very inflammable, and generates during combustion much sulphurous acid: on this account its presence in coal-gas is very injurious, and as there is no known means of removing it on a large scale by any method of purification, its non-generation in the process of gas-making becomes a problem of great importance. Few attempts have yet been made to solve this difficulty, but Mr. Wright, the eminent engineer of the Western Gas Company, has observed that its formation is greatly hindered, if not entirely prevented, by the employment of a somewhat

moderate temperature. In corroboration of this, I have frequently had occasion to notice that the gas furnished by companies who use a high heat contains a very large quantity of this noxious material, whilst gas generated at lower temperatures—as, for instance, that produced by White's hydrocarbon process—contains mere traces of this compound. Although no process for the absorption of bisulphuret of carbon vapour from coal-gas is sufficiently cheap for employment on a large scale, yet advantage might be taken of its solubility in a solution of caustic potash in fousel oil (a bye-product in spirit distilleries), for its removal from the gas supplied to private houses, where the damage done by the sulphurous acid is most annoying: by passing the gas over a considerable surface of this solution, contained in a small private purifier, the bisulphuret of carbon vapour is completely removed.

Bisulphuret of carbon vapour can be readily detected in coal-gas by a very simple apparatus devised by Mr. Wright*: in this instrument the products of the combustion of a jet of gas are made to pass through a small Liebig's condenser; if the liquid dropping from this condenser strongly redden blue litmus-paper, it is highly probable that bisulphuret of carbon is present. As a decisive test, fifty or sixty drops of the condensed fluid should be collected in a small test-tube, and a few drops of pure nitric acid added: on heating this mixture to boiling over a spirit-lamp, and then adding a drop or two of a solution of chloride of barium, the liquid will become more or less milky if bisulphuret of carbon has been present in the gas. It is necessary here to remark, that the absence of sulphuretted hydrogen must be first ascertained by the non-coloration of paper imbued with acetate of lead, and held for some minutes in a stream of the gas.

Sulphuretted Hydrogen.—This gas is formed by the conjunction of hydrogen and sulphur at a red heat; it is hence always an ingredient in crude coal-gas, but can be perfectly removed by various processes of purification. It can be prepared pure by decomposing protosulphuret of iron with dilute sulphuric acid, and collecting the evolved gas at the pneumatic trough or over mercury.

Sulphuretted hydrogen is a colourless gas, of a very nauseous odour resembling that of putrid eggs; its specific gravity is 1·1747. It is highly inflammable, burning with a blue flame destitute of light and generating a large amount of sulphuric acid: it is chiefly this latter circumstance which renders its presence in coal-gas objectionable. It is readily absorbed by metallic solutions, by oxide

* This instrument, indispensable to every gas-manufacturer, can be had, I believe, on application to Mr. Wright, engineer to the Western Gas Company, Paddington.

of iron, and by lime, both in the wet and dry state, and is easily recognized in coal-gas by exposing a strip of paper impregnated with acetate of lead to a stream of the gas—if the paper become discoloured, sulphuretted hydrogen is present.

Cyanogen.—Cyanogen is generated in small quantities during the destructive distillation of coal; it unites immediately with ammonia or with sulphide of ammonium, forming either cyanide of ammonium or sulphocyanide of ammonium, both of which dissolve in the so-called gas-liquor. Cyanogen in its pure state is a colourless gas, of a peculiar odour, and is very poisonous. It is inflammable, burning with a crimson flame. United with hydrogen, it forms hydrocyanic (prussic) acid, and combined with iron it generates Prussian blue. A patent was some years ago taken out for the preparation of Prussian blue from the refuse matters of gas-works, but the process never came into operation, as the quantity of cyanogen was too minute to repay the labour of extraction.

ON THE GENERATION OF COAL-GAS.

The common process of making gas is too well known to require consideration here, and the methods of purification being described in another part of this work need not be now discussed; there are however some chemical considerations of a general character connected with the generation of gas which may be now appropriately brought forward.

The constituents of purified coal-gas are hydrogen, light carburetted hydrogen, carbonic oxide, olefiant gas, other illuminating gases having the general formula $C_n H_n$—that is, containing an equal number of atoms of carbon and hydrogen, like olefiant gas; further, the vapours of hydrocarbons having the formula $C_n H_{(n-6)}$, in which the atoms of carbon exceed those of hydrogen by six, as benzole; and probably other hydrocarbons whose composition is not yet known. In addition to these, there are also present small quantities of nitrogen, oxygen, and bisulphuret of carbon vapour, which however, for our present purpose, may be entirely neglected.

It has generally been assumed that hydrogen and carbonic oxide possess no illuminating power, and that the light afforded by coal-gas is due to light carburetted hydrogen, olefiant gas, and other hydrocarbons; but late experiments have proved that light carburetted hydrogen possesses, in a practical point of view, no

illuminating power whatever; and we must therefore ascribe all the light of coal-gas to the olefiant gas and hydrocarbons contained in it, whilst the relative proportions of hydrogen, light carburetted hydrogen, and carbonic oxide, with which these luminiferous ingredients are diluted, exercise no influence upon the amount of light yielded by a given volume of these illuminating compounds.

The constituents of coal-gas, and also of other gases used for illuminating purposes, may therefore be divided into two classes, viz. luminous and non-luminous constituents: to the first belong olefiant gas and the rest of the hydrocarbons mentioned above; to the second, hydrogen, carbonic oxide, and light carburetted hydrogen. To the first class alone is the illuminating power of every gaseous mixture due, but at least one member of the second class is also indispensable, since otherwise the combustion of the hydrocarbons, without the production of much smoke and a consequent loss of light, would be attended with much difficulty. The members of the first class are all instantaneously decomposed at a white heat: they all deposit their carbon at this temperature in the form of exceedingly fine particles, which form so many centres for the radiation of light in the flame of a gas-light. The greater the number of such particles that are at any moment present in a flame, the greater is the amount of light emitted by that flame. These considerations render it evident that the value of these hydrocarbons as light-yielding materials is in direct proportion to the quantity of carbon contained in a given volume, and is quite independent of the volume of hydrogen combined with that carbon; the densest of the gases or vapours of the first class are therefore those which possess the highest illuminating power. All the members of this class are however, as just mentioned, more or less rapidly decomposed at a red heat, and in the usual process of gas-making the inner walls of the retorts soon become covered with a layer of carbon derived from this source. This destruction of luminiferous constituents is dependent, on the one hand, upon the length of time during which they are exposed to a high temperature, and on the other, upon the number of the particles of such constituents which come in contact with the red-hot sides of the retort. Two methods therefore suggest themselves for the prevention of this decomposition: the first would consist in the rapid removal of the gases from the retort, and the second in the dilution of the luminous gases by an admixture of non-luminous constituents, for it is evident that the number of atoms of illuminating gas, in contact with a given surface, would only be half as great if that gas were diluted with an equal volume of hydrogen as it would be without such admixture.

Both these methods of preservation have been combined in an improved process of gas-generation lately introduced, and known under the name of White's hydro-carbon process: the results which have been obtained by the application of this new process are highly remarkable, and fully bear out the principles just laid down; the following results of two parallel experiments upon Boghead Cannel will serve as an illustration*:—

CUBIC FEET OF GAS PER TON.		ILLUMINATING POWER PER TON IN SPERM CANDLES.		GAIN PER TON BY WHITE'S PROCESS.		GAIN PER CENT. BY WHITE'S PROCESS.	
By old process.	By White's process.	By old process.	By White's process.	Quantity of gas in cubic feet.	Illuminating power in sperm candles.	Quantity of gas.	Illuminating power.
13,240	38,160	11,340	21,368	24,920	10,028	178·2	88·4

Thus in the distillation of one ton of Boghead Cannel a quantity of hydrocarbons have been saved from destruction equal to 10,028 sperm candles, each burning ten hours at the rate of 120 grains per hour.

Analyses of the gases produced in the above experiments proved that a large proportion of the increase in the quantity of gas obtained by the new process was hydrogen mixed with a small proportion of carbonic oxide—two gases belonging to the second or non-illuminating class. Besides the use of the members of this second class which has been already stated, they are valuable as forming a medium for the solution of the vapours of such hydrocarbons as exist in the liquid or even solid state, at the ordinary temperature of the atmosphere; they thus enable us to convert an additional quantity of illuminating materials into the gaseous form, which they retain permanently, unless the temperature fall below the point of saturation. The gain in illuminating power which is thus obtained will be perhaps better seen from the following example. If 100 cubic inches of olefiant gas, being allowed to saturate itself with the vapour of a volatile hydrocarbon containing three times the amount of carbon in a given volume of its vapour as that contained in an equal volume of olefiant gas, took up or dissolved in this

* For further particulars of and experiments on this new process, see Reports on the Manufacture, Composition, and Illuminating Power of White's Patent Hydrocarbon Gas, by S. Clegg, Esq., sen., and Dr. Frankland.

way three cubic inches of hydrocarbon vapour, then, if we express the value in illuminating power of one cubic inch of olefiant gas as unity, the illuminating power of the 103 cubic inches of the mixture of olefiant gas and hydrocarbon vapour will be 109; now if we mix these 103 cubic inches with 100 cubic inches of hydrogen, the mixture will be able to take up an additional three cubic inches of the hydrocarbon vapour, and the illuminating power of the 206 cubic inches will then become 118. Thus the hydrogen produces a gain in illuminating power equal to nine cubic inches of olefiant gas, or nearly 4·5 per cent. upon the total volume of mixed gases. When we consider that coal naphtha contains hydrocarbons of great volatility, and which are no doubt the surplus remaining after the saturation of the gas from which they have condensed, the importance of this function of the non-illuminating class of combustible gases will be sufficiently evident. It is necessary here to remark that incombustible gases could not be employed for this purpose, since their cooling influence upon the flame during the subsequent burning of the gas would diminish the light to a far greater extent than the hydrocarbon vapour could increase it.

It is evident that all the three non-illuminating gases forming the second class would perform both the offices assigned to them equally well; we have as yet therefore seen no reason for giving our preference in favour of any one of these diluents. If however we study their behaviour during combustion, we shall find that where the gas is to be used for illuminating purposes, hydrogen has qualities which give it a decided preference over the other two. When gas is used for lighting the interior of public buildings and private houses, it is very desirable that it should deteriorate the air as little as practicable, or in other words, it should consume as small a quantity of oxygen and generate as little carbonic acid as possible; the oppressive heat which is often felt in apartments lighted with gas also exemplifies the great advantage of its generating a minimum amount of heat. The heating powers of hydrogen, light carburetted hydrogen, and carbonic oxide have been given in the description of each of these gases, and from a comparison of their heating powers, together with the deteriorating effect upon the atmosphere, it will be seen that light carburetted hydrogen is very objectionable as a diluent, not only on account of the carbonic acid which it generates and the large quantity of oxygen it consumes, but also by reason of the very great amount of heat which in relation to its volume it evolves on combustion, the absolute thermal effect being more than three times as great as that of either of the other gases. The quantity of heat evolved by the combustion of equal volumes of car-

bonic oxide and hydrogen is nearly, and the amount of oxygen consumed quite the same; but the quantity of carbonic acid evolved by the first gives a decided preference to hydrogen as the best diluent. The same comparison also shows that where the gas is to be used for heating purposes, and the products of combustion are carried away, light carburetted hydrogen is the best diluent.

These remarks indicate the objects that should be chiefly regarded in the generating department of the manufacture of gas for illuminating purposes: these are—

1. The formation of a due proportion of illuminating and non-illuminating constituents, so that on the one hand the combustion of the gas shall be perfect, and without the production of smoke or unpleasant odour, and on the other the volume of gas required to produce a certain amount of light shall not be too great.

2. The extraction of the largest possible amount of gaseous illuminating compounds from a given weight of materials.

3. The presence of the largest possible proportion of hydrogen amongst the non-illuminating constituents, to the exclusion of light carburetted hydrogen and carbonic oxide, so as to produce the least amount of atmospheric deterioration in the apartments in which the gas is consumed.

ON THE ANALYSIS OF COAL-GAS.

The accurate analysis of gaseous mixtures is one of the most delicate operations of modern chemistry. This arises not only from the difficulty of preserving gases during the requisite manipulations free from admixture with atmospheric air, but also from the circumstance that their volume, the measurement of which is in most cases our only means of estimating their quantity, is liable to constant and considerable change by fluctuations of temperature and of the pressure of the atmosphere, as well as by the dryness or moisture of the gas itself. This branch of chemical analysis owes much of its present accuracy and perfection to the researches of Professor Bunsen.

All analytical operations upon gases must be conducted over mercury, which metal should be placed in a small wooden pneumatic trough with plate-glass sides. The endiometers, or measuring tubes, should be accurately calibrated and graduated into cubic inches and tenths of a cubic inch, the tenths being subdivided by the eye into hundredths when the volume of a gas is read off: this latter division is readily at-

tained by a little practice. At each determination of volume it is necessary that the gas should either be perfectly dry or quite saturated with moisture. The first condition is attained by placing in the gas for half an hour a small ball of fused chloride of calcium attached to a platinum wire*; the second condition, by introducing a minute drop of water into the head of the eudiometer before filling it with quicksilver. The determinations of volume must either be made when the mercury is at the same level inside and outside the eudiometer, or, as is more frequently done, the difference of level must be accurately measured in the subsequent reduction to a standard pressure. The height of the barometer and the temperature of the surrounding atmosphere must also be observed each time the volume of gas is measured, and proper corrections made for pressure, temperature, and also the tension of aqueous vapour if the gas be moist. As tables and rules for these corrections are given in most treatises on chemistry, they need not be repeated here.

The process of gas analysis described below has reference to purified coal-gas, the method of detecting the several impurities having been already given in the description of the compounds constituting such impurities.

I. Estimation of Carbonic Acid.

A few cubic inches of the gas are introduced into a short eudiometer, moistened as above described; the volume is accurately noted, with the proper corrections, and a bullet of caustic potash is then passed up through the mercury into the gas: it is allowed to remain for at least one hour; the volume of the gas, being again ascertained and subtracted from the first volume, gives the amount of carbonic acid which has been absorbed by the potash.

II. Estimation of Oxygen.

This gas can be very accurately estimated by Liebig's new method, which depends upon the rapid absorption of oxygen by an alkaline solution of pyrogallic acid. To apply this solution, a small test-tube is filled with quicksilver, and in-

* These balls, which should be of the size of a large pea, are required constantly in operations upon gases: they are readily prepared when the substance of which they are formed is fusible by heat, as chloride of calcium or caustic potash, by melting these materials in a crucible and then pouring them into a small bullet-mould in which the curved end of a platinum wire has been placed; when quite cold the ball attached to the wire is readily removed from the mould. Coke-bullets are made by filling the mould containing a platinum wire with a mixture of two parts of coke and one of coal, both finely powdered, and then exposing the mould and its contents to a heat gradually increased to redness, for a quarter of an hour.

verted in the mercury trough, a few drops of a saturated solution of pyrogallic acid in water are thrown up into this tube by means of a pipette, and then a similar quantity of a strong solution of potash; a coke bullet attached to a platinum wire is introduced into this liquid, and allowed to saturate itself; it is then withdrawn, and conveyed carefully below the surface of the mercury into the eudiometer containing the residual gas of experiment No. I.: every trace of oxygen will be absorbed in a few minutes, and the volume being again measured, the diminution from the last reading will represent the amount of oxygen originally present in the gas. It is essential that the coke bullet, after saturation with the alkaline solution of pyrogallic acid, should not come in contact with the air before its introduction into the gas.

III. Estimation of the Luminiferous Constituents.

Various methods have been employed for the estimation of the so-called olefiant gas (luminiferous constituents) contained in coal-gas. The one which has been most generally employed depends upon the property which is possessed by olefiant gas and most hydrocarbons, of combining with chlorine, and condensing to an oily liquid: hydrogen and light carburetted hydrogen are both acted upon in a similar manner, when a ray even of diffused light is allowed to have access to the mixture; but the condensation of the olefiant gas and hydrocarbons takes place in perfect darkness, and advantage is therefore taken of this circumstance to observe the amount of condensation which takes place when the mixture is excluded from light; the volume which disappears during this action of the chlorine is regarded as indicating the quantity of olefiant gas present in the mixture. There are many sources of error inseparably connected with this method of operating, which render the results unworthy of the slightest confidence; the same remark applies also to the employment of bromine in the place of chlorine: in addition to the circumstance that these determinations must be made over water, which allows a constant diffusion of atmospheric air into the gas, and *vice versâ*, there is also formed in each case a volatile liquid, the tension of the vapour of which increases the volume of the residual gas, and this increase admits of neither calculation nor determination. The only material by which the estimation of the luminiferous constituents can be accurately effected is anhydrous sulphuric acid, which immediately condenses the luminiferous constituents of coal-gas, but has no action upon the other ingredients, even when exposed to sunlight. The estimation is conducted as follows:—A coke bullet, prepared as described above, and attached to

a platinum wire, being rendered thoroughly dry by slightly heating it for a few minutes, is quickly immersed in a saturated solution of anhydrous sulphuric acid in Nordhausen sulphuric acid, and allowed to remain in the liquid for one minute; it is then withdrawn, leaving as little superfluous acid adhering to it as possible, and quickly plunged beneath the quicksilver in the trough, and introduced into the same portion of dry gas, from which the carbonic acid and oxygen have been withdrawn by experiments Nos. I. and II.: here it is allowed to remain for about two hours, in order to ensure the complete absorption of every trace of hydrocarbons. The residual volume of gas cannot however yet be determined, owing to the presence of some sulphurous acid derived from the decomposition of a portion of the sulphuric acid: this is absorbed in a few minutes by the introduction of a moist bullet of peroxide of manganese, which is readily made by converting finely powdered peroxide of manganese into a stiff paste with water, rolling it into the shape of a small bullet, and then inserting a bent platinum wire, in such a manner as to prevent its being readily drawn out; the ball should then be put in a warm place, and allowed slowly to dry, it will then become hard, and possess considerable cohesion, even after being moistened with a drop of water previous to its introduction into the gas. After half an hour, the bullet of peroxide of manganese may be withdrawn and replaced by one of caustic potash, to remove the watery vapour introduced with the previous one; at the end of another half-hour this bullet may be removed, and the volume of the gas at once read off. The difference between this and the previous reading gives the volume of the luminiferous constituents contained in the gas. This method is very accurate; in two analyses of the same gas the per-centage of luminiferous constituents seldom varies more than ·01 or ·02 per cent.

IV. Estimation of the Non-Luminous Constituents.

These are light carburetted hydrogen, hydrogen, carbonic oxide, and nitrogen. The per-centages of these gases is ascertained in a graduated eudiometer, about two feet in length, and three-fourths of an inch internal diameter, the thickness of the glass being not more than one-tenth of an inch. This eudiometer is furnished, at its closed end, with two platinum wires, fused into the glass, for the transmission of the electric spark. A drop of water, about the size of a pin's head, is introduced into the upper part of the eudiometer, before it is filled with mercury and inverted in the mercurial trough: this small quantity of water serves to saturate with watery vapour the gases subsequently introduced. About a cubic inch of

the residual gas from the last determination is passed into the eudiometer, and its volume accurately read off; about four cubic inches of pure oxygen are now introduced, and the volume (moist) again determined. The oxygen is best prepared at the moment when it is wanted, by heating, over a spirit or gas flame, a little chlorate of potash, in a very small glass retort, allowing of course sufficient time for every trace of atmospheric air to be expelled from the retort before passing the gas into the eudiometer. The open end of the eudiometer must now be pressed firmly upon a thick piece of India-rubber, placed at the bottom of the trough, and an electric spark passed through the mixture: if the above proportions have been observed, the explosion will be but slight, which is essential if nitrogen be present in the gas, as this element will otherwise be partially converted into nitric acid, and thus vitiate the results; by using a large excess of oxygen, all danger of the bursting of the eudiometer by the force of the explosion is also avoided. The volume after explosion being again determined, a bullet of caustic potash is introduced into the gas, and allowed to remain so long as any diminution of volume takes place: this bullet absorbs the carbonic acid that has been produced by the combustion of the light carburetted hydrogen and carbonic oxide, and also renders the residual gas perfectly dry: the volume read off after this absorption, when deducted from the previous reading, gives the volume of carbonic acid generated by the combustion of the gas.

The residual gas now contains only nitrogen and the excess of oxygen employed. The former is determined by first ascertaining the amount of oxygen present, and then deducting that number from the volume of both gases: for this purpose a quantity of dry hydrogen, at least three times as great as the residual gas, is introduced, and the volume of the mixture determined; the explosion is then made as before, and the volume (moist) again recorded: one-third of the contraction caused by this explosion represents the volume of oxygen, and this deducted from the volume of residual gas, after absorption of carbonic acid, gives the amount of nitrogen.

The behaviour of the other three non-luminous gases on explosion with oxygen enables us readily to find their respective amounts by three simple equations, founded upon the quantity of oxygen consumed, and the amount of carbonic acid generated by the three gases in question. Hydrogen consumes half its own volume of oxygen, and generates no carbonic acid; light carburetted hydrogen consumes twice its volume of oxygen, and generates its own volume of carbonic acid; whilst carbonic oxide consumes half its volume of oxygen, and generates its own volume of car-

bonic acid. If therefore we represent the volume of the mixed gases by A, the amount of oxygen consumed by B, and the quantity of carbonic acid generated by C, and, further, the volumes of hydrogen, light carburetted hydrogen, and carbonic oxide respectively by x, y, and z, we have the following equations:—

$$x + y + z = A$$
$$\tfrac{1}{2}x + 2y + \tfrac{1}{2}z = B$$
$$y + z = C$$

from which the following values for x, y, and z are derived:—

$$x = A - C$$
$$y = \frac{2B - A}{3}$$
$$z = C - \left(\frac{2B - A}{3}\right)$$

V. Estimation of the Value of the Luminous Constituents.

We have now given methods for ascertaining the respective quantities of all the ingredients contained in any specimen of coal-gas, but the results of the above analytical operations afford us no clue to its illuminating power; they give us, it is true, the amount of illuminating hydrocarbons contained in a given volume of the gas, but it will be evident, from what has already been said respecting the luminiferous powers of these hydrocarbons, that the greater the amount of carbon contained in a given volume, the greater will be the quantity of light produced on their combustion; and therefore, as the number of volumes of carbon vapour contained in one volume of the mixed constituents, condensable by anhydrous sulphuric acid, has been found to vary from 2·54 to 4·36 volumes, it is clear that this amount of carbon vapour must be accurately determined for each specimen of gas, if we wish to ascertain the value of that gas as an illuminating agent. Fortunately this is easily effected, for if we ascertain the amount of carbonic acid generated by 100 volumes of the gas in its original condition, knowing from the preceding analytical processes the per-centage of illuminating hydrocarbons, and also the amount of carbonic acid generated by the non-luminous gases, we have all the data for calculating the illuminating value of the gas. For this purpose a known volume of the original gas (about one cubic inch) is introduced into the explosion eudiometer, and mixed with about five times its volume of oxygen, the electric spark is passed, and the volume of carbonic acid generated by the explosion ascertained as above directed. If we now designate the per-centage of hydro-

carbons absorbed by anhydrous sulphuric acid by A, the volume of carbonic acid generated by 100 volumes of the original gas by B, the carbonic acid formed by the combustion of the non-luminous constituents remaining after the absorption of hydrocarbons from the above quantity of original gas by C, and the volume of carbonic acid generated by the combustion of the luminiferous compounds (hydrocarbons) by x, we have the following equation:—

$$x = C - B$$

and therefore the amount of carbonic acid generated by one volume of the hydrocarbons is represented by

$$\frac{C - B}{A}$$

But as one volume of carbon vapour generates one volume of carbonic acid, this formula also expresses the quantity of carbon vapour in one volume of the illuminating constituents. For the purpose of comparison however it is more convenient to represent the value of these hydrocarbons in their equivalent volume of olefiant gas, one volume of which contains two volumes of carbon vapour; for this purpose the last expression need only be changed to

$$\frac{C - B}{2A}$$

Thus, if a sample of gas contain 10 per cent. of hydrocarbons, of which one volume contains three volumes of carbon vapour, the quantity of olefiant gas to which this 10 per cent. is equivalent will be 15.

By the application of this method we obtain an exact chemical standard of comparison for the illuminating value of all descriptions of gas; and by a comparison of the arbitrary numbers thus obtained, with the practical results yielded by the same gases when tested by the photometer, much valuable and useful information is gained.

Estimation of the Specific Gravity of Gas.

Although the mere determination of the specific gravity of gases is of very little use as a test of their commercial value (unless the gas is to be used for ballooning), yet, as it is still much employed by gas engineers, and as such an estimation is occasionally useful for controlling the results of the chemical analysis, a method by which the specific gravity of gas can be readily and correctly determined is here subjoined.

The specific gravity of gases should be taken in a room where there is no fire,

and where the temperature is liable to little variation during the time occupied in the operations. The following apparatus is necessary:—First, a thin glass globe, capable of holding at least 200 cubic inches, and furnished with a brass cap and stopcock, so accurately fitted as to prevent all ingress of air when the globe is exhausted; secondly, a small exhausting syringe, or air-pump, to which the above globe can be screwed air-tight; thirdly, a balance, capable of weighing to one-fiftieth of a grain, when loaded with a quarter of a pound in each pan; fourthly, a glass tube, eighteen inches long, and half an inch diameter, filled with fragments of fused chloride of calcium, and closed at each end with a cork, perforated with a piece of glass tube, of such dimensions as to be capable of being adapted, by caoutchouc joints, at one end to the exit-pipe of a small gas-holder, and at the other to the stopcock of the glass globe. The process consists in ascertaining the weight of equal volumes of atmospheric air, and the gas under investigation at the same temperature and pressure. This is accomplished by first exhausting the globe by means of the syringe or air-pump, and then accurately ascertaining its weight, care being taken to allow time for the globe to assume the same temperature as that of the air surrounding the balance; the globe should then be connected with one extremity of the chloride of calcium tube, by means of a piece of vulcanized caoutchouc tube, and the stopcock being then very slightly opened, the air passing through the chloride of calcium tube should be allowed slowly to fill the globe: in its passage through the fragments of chloride of calcium, the air becomes thoroughly deprived of watery vapour. The globe should now be detached from the drying tube, and replaced in the balance, where it should remain undisturbed for at least five minutes; the stopcock should be now opened for a moment, to equalize the pressure within and without, and the weight then accurately determined: the difference between the two weighings gives the weight of the air enclosed in the globe. The chloride of calcium tube should now be attached to the exit-pipe of the gas-holder, and a stream of gas allowed to rush through it until every trace of air has been expelled from the interstices of the chloride of calcium; the globe, again exhausted, is then to be attached to the other extremity of this tube, and the stopcock being slightly opened as before, the gas, perfectly dried in passing over the chloride of calcium, is allowed slowly to fill the globe, which should, whilst still attached to the drying tube, be allowed to stand undisturbed for a few minutes near the balance, before the stopcock is finally closed and detached from the drying tube. The weight of the globe thus filled with dry gas is then ascertained, and that of the exhausted globe being subtracted from it,

the difference gives, of course, the weight of the gas. We have now the weight of equal volumes of gas and atmospheric air at the same temperature and pressure: the weight of the former divided by that of the latter is the specific gravity of the gas. Thus, suppose the weight of the exhausted globe to be 2000 grains, that of the globe filled with dry air 2060 grains, and with dry gas 2040 grains; the weight of the volume of air equal to the contents of the globe would be 60 grains, and that of the same volume of gas 40 grains, hence $\frac{40}{60} = \cdot 6666 =$ specific gravity of gas; that of air being taken as unity.

Unless a number of specific gravities are determined at the same time, it is indispensably necessary to ascertain the weight of the air contained in the globe previous to each determination. Care should be taken that the temperature of the room in which the balance is placed does not vary more than about one degree between the several weighings of the globe, as otherwise a considerable error will be introduced into the experiments. The globe should also be protected, as much as possible, from the heat radiating from the body of the operator during the several weighings.

COAL.

Geologists agree in admitting coal to be of vegetable origin; impressions of various plants, such as Fern and Calamites, and sometimes trunks of trees, having frequently been found in many kinds. A decisive proof of the vegetable origin, even of the most perfect bituminous coal, has been discovered by Mr. Hutton: he has ascertained that if any of the three varieties of coal found near Newcastle be cut into very thin slices and submitted to the microscope, more or less of vegetable structure can be recognized*.

* "In these varieties of coal, says Mr. Hutton, even in samples taken indiscriminately, more or less of vegetable texture could always be discovered, thus affording the fullest evidence, if any such proof were wanting, of the vegetable origin of coal.

"Each of these three varieties of coal, besides the fine distinct reticulation of the original vegetable texture, exhibits other cells, which are filled with a light wine-coloured matter, apparently of a bituminous nature, and which is so volatile as to be entirely expelled by heat before any change is effected in the other constituents of the coal. The number and appearance of these cells vary with each variety of coal. In caking coal the cells are comparatively few, and are highly elongated; in the finest portions of this coal, where the crystalline structure, as indicated by the rhomboidal form of its fragments, is most developed, the cells are completely obliterated. The slate coal contains two kinds of cells, both of which are filled with yellow bituminous matter: one kind is that already noticed in caking coal, while the other kind of cells constitute groups of smaller cells, of an elongated circular figure. In those varieties which go by the name of Cannel Parrot and Splint Coal, the crystalline structure, so conspicuous in fine caking coal, is wholly wanting; the first kind of cells are rarely seen, and the whole surface displays an almost uniform series of the second class of cells, filled with bituminous matter, and separated from each other by thin fibrous divisions. Mr. Hutton considers it highly probable that these cells are derived from the reticular texture of the parent plant, rounded and confused by the enormous pressure to which the vegetable matter has been subject.

"The author next states, that though the crystalline and uncrystalline, or, in other terms, perfectly and imperfectly developed varieties of coal generally occur in distinct strata, yet it is easy to find specimens which in the compass of a single square inch contain both varieties. From this fact, as also from the exact similarity of position which they occupy in the mine, the differences in different varieties of coal are ascribed to original difference in the plants from which they were derived."—*Dr. Buckland's Bridgewater Treatise.*

Coal is classed amongst the Carboniferous group, and is interstratified with sandstone, limestone, and shale, in the south-west of England and in South Wales resting upon Old Red Sandstone. In Yorkshire and the northern counties a slight intermixture of mountain limestone is found with the coal-measures; and after passing through the millstone grit, several hundred feet of complex deposit is found of limestones, coal-bearing sandstones, and shale, below which is the great bed of mountain limestone. "Some of the coal-measures are of fresh-water origin, and may have been formed in lakes; others seem to have been deposited in estuaries, or at the mouths of rivers, in spaces alternately occupied by fresh and salt water*." There are fresh-water strata in the coal-field of Yorkshire, some of which contain shells. The great field from which coal for the purpose of gas-making is obtained is in the neighbourhood of Newcastle-upon-Tyne. This coal has no regular form or structure; its lustre is resinous, more or less distinct; colour black, passing in earthy varieties into greyish tints, frequently with an iridescent tarnish. When broken it assumes a cubic or rhombo-prismoidal form; it is lamellar in one direction, sometimes in two.

Most varieties of coal contain sulphur and other minerals, together with saline matter; the specific gravity is from 1·271 to 1·352,—water being unity. The varieties possessing the most resinous fracture, being compact in one direction, viz. at right angles to the lamellæ, contain the most bitumen, and are the best for the production of gas†.

Haidinger, in his translation of Mohs's work on Mineralogy, makes the following observations on coal:—

"*Bituminous Mineral Coal.*—No regular form or structure; fracture conchoidal, uneven; lustre resinous, more or less distinct; colour black or brown, passing, in earthy varieties, into greyish tints; streak unchanged, except that it sometimes becomes shining-opake; sectile in different degrees; hardness = 1·0 to 2·5. Sp. gr. = 1·223, moor coal from Töplitz; = 1·270, common brown coal from Eibiswald, in Styria; = 1·271, black coal from Newcastle; = 1·288, bituminous wood; = 1·329, common brown coal from Leoben, in Styria; = 1·423, 1·25, cannel coal from Wigan, in Lancashire.

* Lyell's Elements of Geology, p. 422.

† A shining fracture is by no means a criterion for a bituminous coal, for some Anthracites, perfectly non-bituminous, are peculiarly bright: the *resinous* lustre is a better guide, but requires a person habitually acquainted with such matters to give anything approaching to a correct opinion of the quality of a coal from the appearance of its fracture.

"*Compound Varieties.*—Massive; composition lamellar; faces of composition smooth and even, different gradations; granular texture; often impalpable, and then fracture is uneven, even, or flat conchoidal. Ligniform shapes, the structure of which resembles that of wood, sometimes very distinct, but often obliterated, with the exception of some slight traces: fracture then becomes conchoidal, particularly across the fibres. There are some earthy varieties of a loose friable texture."

In the species of bituminous mineral coal are comprised the *Brown* and *Black Coal* of Werner, excepting the Columnar Coal, which belongs to the new bituminous class (Mohs, vol. iii. p. 62); these two kinds however, and still more the varieties they contain, are very difficult to be distinguished: colour, structure, and the kind of lustre which depends upon the latter, are almost all that remain to mark their distinction. The colour of *Brown Coal*, as the name imports, is brown; it possesses a ligneous structure, or consists of earthy particles: the colour of *Black Coal* is black, not inclining to brown, and it does not possess the structure of wood. The varieties of brown coal are the following:—*Bituminous Wood*, Lignite, or Bovey coal, which presents a ligneous texture, and very seldom anything like conchoidal fracture, imperfect and without lustre: it is brittle, and leaves a considerable quantity of white ash when burned*. *Earthy Coal*, consisting of loose friable particles. *Moor Coal*, or trapezoidal brown coal, distinguished by the absence of ligneous structure, by the property of bursting and splitting into angular fragments when removed from its original repository, and the low degree of lustre upon its imperfect conchoidal fracture. *Common Brown Coal*, which, though it shows traces of ligneous texture, is of a more firm consistency than the rest of the varieties, and possesses high degrees of lustre upon its more perfect conchoidal fracture. *Slate Coal* possesses a more or less coarse slaty structure, which however seems to be rather a kind of lamellar composition than real fracture.

All these varieties are objectionable for the production of gas, owing as well to the extraneous matter contained in them, as to the deficiency of their products in distillation. The following varieties may easily be distinguished by a little practice, and are all economical. *Pitch Coal* is of a velvet-black colour, generally inclining to brown, with a strong lustre, and presenting in every direction large and perfect conchoidal fracture. *Foliated* and *Coarse Coal* have both a lustrous

* This coal has lately been applied to the firing of earthenware at the Bovey Tracey Pottery, Devon.

fracture, but approach more to a granular appearance. *Cannel Coal* is without visible composition, and has a flat conchoidal fracture in every direction, with but little lustre, by which it is distinguished from pitch coal; it is most like the moor coal, but the difference in their specific gravity is greater than between almost any other two varieties, by which it is the best distinguished. Sp. gr. of cannel coal, 1·4; sp. gr. of moor coal, 1·10. *Peacock* or *Iridescent Coal* is so called from the peculiar tints of colour which it shows, and which appear to be generally the result of some action of water on the surface and between the natural faces. This tarnish, rare in most collieries, appears to be particularly abundant in the old Silkstone Colliery, near Barnsley, Yorkshire: it is not quite clear whether it arises from a very thin film of foreign matter deposited on its surface, or whether the mechanical condition of the surface itself (as in the case of mother-of-pearl) produces the appearance of iridescence.

The transitions between the varieties of coal are hardly perceptible, and it requires the nicest judgement to detect the good from the bad. They all consist of bitumen and carbon in various proportions, are more or less easily inflammable, and burn with flame and a bituminous smell; several varieties become soft, which is invariably an excellent criterion for valuable coal; others coke when kindled, and leave a more or less earthy residue.

The varieties called slate coal, foliated coal, coarse coal, and pitch coal, occur chiefly in the coal formation; some varieties of pitch coal, and also the moor coal, bituminous wood, and common brown coal, are met with in the formations above the chalk; the earthy coal, and some varieties of bituminous wood and common brown coal, are often included in diluvial and alluvial detritus. In the neighbourhood of Garstang and of Lancaster these latter varieties are met with beneath a bed of peat thirty feet deep: fossil trunks of trees, hazel-nuts, and many kinds of bark and ferns are abundant.

The Anthracite is a slaty, glance coal, perfectly free from bitumen, and therefore totally unfit for purposes of gas manufacture. The most perfect anthracite with which we are acquainted is that from Bonville's Court Colliery, near Tenby, in South Wales: its constituents are, carbon 94·18, hydrogen 2·99, nitrogen ·50, sulphur ·59, and ash ·98, and is almost entirely wanting in volatile matter; indeed many of the Welsh coals are inferior in this respect: but their evaporative powers are very high, and they are thus of great value for steam navigation; for instance, while one pound of Wigan Cannel will only evaporate 7·70 lbs. of water from 212° Fahr., the same weight of Bonville's Court anthracite will evapo-

rate 10·55 lbs. of water; and where coal is used as fuel in the retort furnaces this description would be found to produce admirable results.

The Staffordshire bed also furnishes large quantities of coal for the production of gas, and the line between some varieties of these and Newcastle coal can hardly be drawn. They generally require a higher temperature for distillation. The Forest of Dean and Gloucestershire coal generally are also valuable, and work well, though not so productive as the preceding kinds.

The Cannel coal from Wigan in Lancashire, and Lismahago in Scotland, produces gas of better quality and in greater abundance than any other variety; but the lately discovered Boghead coal is probably the richest gas-yielding substance known.

The following brief outlines of the coal-fields of Great Britain may not be without interest, and I commence with the most important to gas-engineers, viz. the great coal-field of Northumberland and Durham, or the Newcastle coal-field, as it is generally termed.

The Newcastle coal-field is estimated to contain upwards of 360,000 acres of productive coal area in the county of Durham, and nearly 150,000 in Northumberland: of this 67,000 acres are now worked, and the average thickness of coal may be regarded as twelve feet; an acre containing 4840 square yards, and each cubic yard of coal being taken to weigh one ton, it may be considered that the coal-field has contained more than ten thousand millions of tons of coal, of which about one-eighth part is probably consumed, and the present annual consumption may be estimated at ten millions of tons, including the quantity destroyed and rendered unserviceable. The qualities of the coal are three—the common caking kinds, coarser kinds called splint coal, and cannel coal. They are all bituminous, but the proportions differ; and the quantity and quality of the gas yielded by them are equally various, that from cannel being by far the richest.

The coal is worked in this field at a very great depth, exceeding in some cases 1800 feet; and the areas worked from one set of pits are often very large, amounting to 500 or even 1000 acres.

The associated beds of the coal-measures are grits and shales, and there are many slips and faults, some of them very considerable. The method of extracting the coal in the Newcastle field is that called *pillar and stall*, which consists in first working a certain proportion of the coal by opening galleries at right angles to each other, leaving large pillars of coal to support the roof. These pillars are afterwards removed, and the roof allowed to sink down, forming what is technically called the *goaf*.

There are nearly two hundred pits or collieries worked in the district: the number of men and boys employed is about 26,000, and the average price of the coal free on board is about 11*s*. per ton. The estimated quantity of coal sold in the year 1847 was 7,730,000 tons.

The great central coal-field of England lies in South Yorkshire, Nottingham, and Derby: it commences about five miles to the north of Leeds, where its breadth is about twenty-five miles, Leeds lying a little to the east of the middle of the line; its length, almost directly south, is fully sixty-five miles, Nottingham being at its extreme south-east point: its south-west point is thirteen miles from Nottingham. Chesterfield, Sheffield, and Wakefield are in the heart of this coal-field, which is at least 650,000 acres in extent. The qualities of coal obtained are bituminous, cannel, and anthracite, varying much in quality in different localities. There are about twelve workable seams, the total average thickness being upwards of thirty feet, and the thickest seam ten feet. The total thickness of the upper carboniferous series here is estimated at about 550 yards.

The method of working the coal is generally on the *long-wall* system, and is distinguished from the Newcastle or *pillar and stall* method, by abstracting at once all available coal, instead of first taking a small proportion, and leaving the rest in the form of pillars. The selection of the method of working should depend on the conditions of the mine; and generally the long-wall system may be considered admissible when iron-stone occurs with the coal, the coal being thin, or the floor and roof soft, the royalty small, the general superincumbent mass compact, and the water not very troublesome. When however there is much gas, when the coal is deep and the quantity to be extracted from one set of workings very considerable, and the water troublesome, it cannot be recommended.

In working the long-wall method, it is usual to put a pair of levels from the shafts, and carry drifts at once to the extremity of the intended workings; and then removing the coal from the end, the roof is allowed to fall, leaving only airway round the outside of the *gob*, or fallen mass, cut in the solid coal. The gob is often partly filled with the rubbish removed in getting the coal.

There are some detached coal-basins, or "*swilleys*," as they are provincially termed, in the northern parts of Yorkshire, but not of sufficient importance to be noticed here.

The Lancashire and Cheshire or Manchester great coal-field, including the Wigan district, ranges nearly fifty miles in length, with a breadth of ten miles on an average; the productive coal-field is thus nearly 400,000 acres, and is divided

into three principal portions, of which the middle one includes the thick coal-seams, worked in various places, Wigan being perhaps the most important. The principal coals are of the caking kind (Arley or Orell main), and a very valuable bed of cannel. Running from the south-east extremity of this large area, in a southerly direction, through Cheshire and into Staffordshire, we find the Cheadle, Macclesfield, and Pottery coal-fields, Newcastle-under-Lyne being at its southern extremity. No other known coal-field contains anything like an equal number and extent of ironstone measures. Towards the northern extremity of Lancashire another coal-field occurs, half-way between Lancaster and Ingleton, but it is of small extent.

The Cumberland or Whitehaven coal-field is a narrow crescent-like belt, extending from Whitehaven to Penrith, being in length about forty-five miles, with a mean breadth of three or four miles.

The south central coal district lies on the borders of Leicestershire and Staffordshire, and occupies also some portions of Warwickshire, South Staffordshire, and Worcestershire.

The Ashby coal-field forms an area of irregular figure, commencing close to Burton-upon-Trent, and running from thence about fifteen miles in the direction of Leicester, with an average breadth of six miles.

The Warwickshire coal-field runs from Tamworth, nineteen miles, in a south-easterly direction to near Coventry and Rugby, with a breadth of about three miles, its north-western extremity swelling out to nearly eight miles.

The Dudley or South Staffordshire and Worcestershire coal-field is an important one considering its limited area: it commences near Rugeley, almost midway in a line drawn from Stafford to Lichfield, and runs from thence in a south-westerly direction fully twenty miles to Stourbridge and Hales Owen, with a breadth of about four miles. The Dudley division is principally celebrated for the ten-yard or thick coal, so named from its being thirty feet thick, and is of excellent quality. When undisturbed by faults and of average quality, this bed of coal, associated with the thin coals and iron-stones, is worth at least £1000 per acre. It was in this district that coal was first used, in the year 1619, for the purpose of smelting iron.

The western coal districts may be divided into the north-western, including the coal-fields of Anglesea and Flintshire; the western, or those of Shropshire; and the south-western, or the three important coal-basins of South Wales, of Monmouthshire, and that of Gloucestershire and Somerset. A remarkable valley

traverses the whole of the island of Anglesea, running nearly parallel with the Menai Straits, and at the distance of about six miles from them: this opens on the south-west into the estuary of Maldraeth, and on the north-east into Red-wharf Bay, and is flanked on both sides by parallel belts of carboniferous lime-stone, in the depression between which coal occurs, the veins of which are thick and extensive.

The North Welsh or Flintshire coal-field is a narrow strip, from two to twelve miles broad, skirting the south-west bank of the estuary of the Dee, and running as far south as Oswestry, the total length from the point of Ayr being forty miles, cut off by a north and south fault. The coal-beds immerge beneath the estuary of the Dee, are discovered again on its opposite side, on the south of the peninsula of Wiral, in Cheshire, where they finally sink beneath superstrata of New Red Sand-stone, and are possibly prolonged beneath these until they re-emerge in the great Lancashire coal-field. This district furnishes some good bituminous coal, cannel, and peacock coal.

The great coal-field of South Wales, extending from Pontypool on the east to St. Bride's Bay on the west, occupies an area of upwards of eight hundred square miles. Both from its extent and the varied character of its numerous beds of coal and iron, it may be considered as the most important of all our coal-fields, not-withstanding that the good *gas*-coal furnished from it is limited in quantity. The upper measures furnish the best red ash coals for household purposes, whilst its lower measures are well adapted for iron-smelting and for boiler-furnaces. In the eastern part of the district the coals are bituminous; as they approach the west they gradually become semi-anthracitic, until in the extreme western district all the coals are anthracite: the dividing line being nearly coincident with the Neath Valley.

The coal-basin of the Forest of Dean forms an irregular elliptical basin, occupying the whole of the forest tract. The longest diameter from north-north-east to south-south-west being about ten miles, the shorter about six, it is understood to occupy about forty-five square miles, the total thickness of the deposits being about three thousand feet, of which there is a thickness of fifty-two feet of coal distributed in twenty-eight seams: it is remarkable for the great regularity of the deposits over a large part of the area, the beds dipping steadily towards the middle of the basin, and the millstone-grit rising and surrounding it; there is however an extensive and remarkable fault crossing the field. The workable seams of the district are in three groups, the lowest of which have not yet been much worked, except near

their outcrop, where they are reached by levels driven from the hill-side. Some parts of the thicker seams measure as much as twelve feet.

Passing by the coal patches of the plain of Shrewsbury as unimportant, we arrive at the Coalbrook Dale coal-field, which ranges from a line drawn from Wellington to Newport, crosses the Severn at Iron Bridge, and runs to within three miles north-west of Bridgenorth: the total length is about twelve miles, and the mean breadth three miles. The upper of these beds are termed stinking coal, and are used only by lime-burners. The best coal usually presents a mixture of slate-coal and pitch-coal, rarely of cannel, and no caking coal. Another coal district is found a few miles to the south of the above, and of equal extent, ranging from near Bridgenorth, and running into Stafford as far as Stourport, on the Severn. The coal measures of Shropshire were probably once connected with those of South Staffordshire; indeed of the identity of some of the measures in the two districts there can be little doubt.

The great south-western coal district includes the South Wales basin, that of the Forest of Dean, and that of South Gloucester and Somerset.

There are three principal coal-basins in Scotland: 1, that of Ayrshire; 2, that of Clydesdale; and 3, that of the valley of the Forth, which runs into the second in the line of the Union Canal. If two lines be drawn, one from St. Andrew's on the north-east coast to Kilpatrick on the Clyde, and another from Haddington to a point a few miles south of Kirkoswald, in Ayrshire, they will include between them the whole space where coal has been worked in Scotland. These districts may be divided into the Lanarkshire or central coal-field, and the great southern coal area, or the Basin of the Clyde, and Glasgow region, which may be subdivided into many others.

The entire area is extremely irregular, and not easy to define, being made up of a number of coal areas, intersected by subordinate formations. It includes the whole of the south side of Fifeshire, a large portion of Lanarkshire (three hundred square miles), portions of Ayrshire and Renfrewshire, East Lothian, Perth, Stirling, Dumbarton, Linlithgow, and Haddington. The united area comprises probably about one thousand six hundred and fifty square miles.

Ireland contains extensive fields of anthracitic and bituminous coal, and doubtless will eventually become rich as a coal country: at present little is worked, and its value is almost unknown. Coal is said to prevail in no less than seventeen counties. Anthracite is found extensively in Leinster and Munster, and bituminous coal in Connaught and Ulster, the former district being the most important.

The Total Area of Coal Measures in England, Scotland, Wales, and Ireland, is as follows, viz.—

	Area of Coal Measures only.		Entire Area.		
	Square Miles.	Acres.	Acres.	Square Miles.	Proportion of Coal to the whole.
In England	6,039	3,864,960	31,770,615	49,643	1-8th
In Scotland and Islands, exclusive of Lakes . .	1,720	1,100,000	18,944,000	29,600	1-18th
In North Wales . . .	210	134,400 }	4,752,000	7,425	1-6th
In South Wales . . .	950	608,000 }			
In Ireland	2,940	1,881,600	20,399,608	31,874	1-18th
In British Isles . . .	—	—	1,119,159	1,748	—
	11,859	7,589,760	76,985,382	120,290	—

Exclusive of wood-coal and lignite formations, and some small undefined areas.

Although the coal formations of Great Britain are of more immediate interest to the English gas-engineer, the science of gas-making is extending so rapidly, and its practice becoming so fully appreciated over the world, that the countries furnishing coal for its production are now noticed. Both in quantity and quality of its coal Great Britain takes the first rank, its annual production being about 32,000,000 tons. Belgium produces annually 5,000,000 tons; France 4,200,000 tons; United States of America nearly 3,000,000 tons of anthracite, and 2,000,000 tons of bituminous coal; Prussia 3,500,000 tons; and Austria about 700,000 tons. With the facilities of transport which railways are fast giving, the production of continental coal will proportionately increase, and it is by no means improbable that in course of time the exportation of gas-coal from England will be very small.

Belgium, in point of rank as a coal-producing country, stands the second in Europe: it is traversed in a direction from nearly west-south-west to east-north-east by a large zone of bituminous coal formation, and may be described under

three principal divisions, viz. the Western or *Hainault* division, which comprises the two basins known as the *Levant* and the *Couchant of Mons*, that of *Charleroi*, and that of *Namur*. The latter lies within the province of Namur; while the two former are within the province of Hainault, stretching into the department du Nord, in France, where their traces are lost a little below Douay.

The Eastern or *Liége* division, commencing in the province of Namur, and embracing a small portion thereof, traverses the province of Liége; directing itself towards Rhenish Prussia, where it communicates with the coal-basins of Eschweiler and Rolduc, and with the Duchy of Limburg, in the Low Countries. The point of division between this and the preceding is said to be the deep and narrow gorge through which the Sampson river flows, in the province of Namur. The whole belt is about one hundred miles in length, or, including its prolongation into France, one hundred and fifty miles. The areas of these fields are as follow:—

1. In the province of Hainault	187,116	English acres
2. In that of Namur	41,125	„ „
3. In that of Liége	103,151	„ „
	331,392	„ „

Being 1-22nd part of the superficies of Belgium.

In the province of Hainault all varieties of coal are met with, from the anthracite to the fattest coals, including the flaming species, locally called *flenu*, approaching to that of Newcastle-upon-Tyne, and adapted for gas-making. The Liége coal furnishes some of excellent quality, the produce being mostly consumed in the district by the many iron-works.

France yields coal from fifty-six out of her eighty-six departments, which are dispersed in eighty-eight principal basins, besides a great number of small detached coal-fields, or deposits less perfectly known. These districts include the bituminous and non-bituminous varieties of coal, anthracite, and lignite.

The production in France cannot be estimated at less than 4,200,000 English tons, while so late as the commencement of the French Revolution all France yielded only 240,000 tons, the greater part from the two principal coal-fields: at that period also France received from abroad full as much coal as her own soil yielded. Now, although the indigenous production has advanced from that period to the present, a space of sixty years, at the enormous rate of upwards of seventeen hundred per cent., and her importations have increased seven hundred and ninety-

two per cent., the quantity of imported coal is more than one-half of the entire amount of native production.

As regards the general *quality* of the coal of France, it is now admitted that it is of an inferior description, and not to be compared with that of Newcastle, Durham, Sunderland, Staffordshire, Wales, or Ireland; consequently when good coals are required, it is to the mines of those districts that the French Government and private companies resort for their supplies. The scarcity and dearness of coal and wood in France, notwithstanding her extensive mines and forests, and the enormous expense of carriage*, form the chief drawbacks to mining and other great undertakings in that country. Even the national steam marine of France derives its chief supplies of coal from Great Britain. Coal is getting more into favour with the French every day: a few years ago you could scarcely meet with a single coal-fire in any house in Paris, now coal-fires are no novelty; so that it may reasonably be expected that, with increased demand and the facilities of railway transport, native coal will be reduced so much in price that it may be employed in gas establishments, without the necessity of receiving aid from abroad. From the distance that the coal-fields lie apart, it can never be supplied at so low a price as in English establishments; yet it may be, and doubtless will be, supplied at one which will remunerate the manufacturing consumers.

America yields bituminous coal and anthracite in abundance, and from her energetic advances in everything relating to trade will doubtless ere long stand second as a coal-producing country, and, as in many other arts, we may expect to find her ere long making rapid progress in gas-lighting. It is true that areas of anthracite extending over a vast tract of country will render the carriage of bituminous coal necessary to those towns lying in the anthracite districts; but her numerous railways will render this transportation a matter of perfect ease. Coal traffic upon railways is becoming a fertile source of revenue. They can compete successfully with the shipping. Therefore not only will gas-coal be carried easily and cheaply within the States, but Canada be supplied, perhaps more certainly and economically than with sea-borne coal. The following table exhibits the areas of her vast coal-fields, according to Mr. S. A. Mitchell, who published them in 1836.

* Coal is much dearer at the pit's mouth in France than in England, and the transport and accessory expenses often augment the price in the proportion of *one* to *six*, and on an average *ten* to *twenty-three;* and this average is too low, because it comprises the total coal extracted, of which a portion is consumed at the pits, without having any new charges to heighten its cost.—*Traité de la fabrication et la fonte du Fer*, p. 1062. *Paris, December*, 1845.

STATES.	Area of the States.	Coal Areas.	Proportion of Coal.	
	Sq. Miles.	*Sq. Miles.*		
1. Alabama . . .	50,875	3,400	1-14th	Bituminous coal.
2. Georgia	58,200	150	1-386th	About the same amount in North Carolina.
3. Tennessee . . .	44,720	4,300	1-10th	
4. Kentucky . . .	39,015	13,500	1-3rd	
5. Virginia	64,000	21,195	1-3rd	
6. Maryland . . .	10,829	550	1-20th	
7. Ohio	38,850	11,900	1-3rd	
8. Indiana	34,800	7,700	1-5th	
9. Illinois	59,130	44,000	3-4ths	
10. Pennsylvania . .	43,960	15,437	1-3rd	Bituminous and anthracite.
11. Michigan . . .	60,520	5,000	1-20th	
12. Missouri . . .	60,384	6,000	1-10th	
	565,283	133,132	nearly 1-4th of twelve States.	

Near Greensburg, in Beaver County, Pennsylvania, is a bed of cannel coal, about eight feet thick, resting upon three feet of ordinary bituminous coal. This cannel is light, compact, ignites with great facility, and burns with a strong bright flame. A similar quality of coal is found in Kentucky, Ohio, Illinois, Missouri, Indiana, and it is believed in Tennessee.

In the above statement deductions have not been made for unproductive areas, for erosions of strata, and for such coal-beds as are never likely to be reached by the miner: nevertheless the actual yielding area is enormous, of whose ultimate value no present estimate can be formed; but if we consider that the American coal-trade commenced in 1820 with 365 tons, and that its present production is 5,000,000 tons, its influence will be felt at no distant period.

Canada, it is pretty clearly ascertained, contains no workable beds of coal; but in other provinces of British America, viz. New Brunswick and Nova Scotia, there are considerable fields of it, and even Newfoundland is said to be rich in this deposit; but the value of any of this coal for gas purposes is, I believe, not known. Some very interesting statistics of these fields might however be given, did the

limits of the present work permit; the reader desirous of further information is referred to Mr. R. C. Taylor's excellent work the 'Statistics of Coal,' published in 1848 by Mr. Chapman, 142, Strand.

The countries producing coal have been mentioned in proportion to their present yield, and it remains shortly to notice Prussia and Austria. The *Zollverein* is very rich in coal-basins; that of La Ruhr, in Westphalia, is the most productive, and possesses common characters with the English coal-fields. *Silesia*, the provinces of the *Lower Rhine*, *Saxony*, *Bavaria*, and the *Duchy of Hesse*, likewise yield this mineral, their relative produce being in the order in which they are set down. Large seams of coal have been discovered at *Buckau*, a small village not far from Berlin: this coal promises to be very abundant. *Peat* is in very extensive use in Prussia, in Bavaria, and Würtemberg: at Berlin and its environs it is employed in almost all the workshops, and on account of its application to the production of gas its consumption is regularly augmenting.

Austria possesses extensive coal-beds, but the working of them has not yet been carried to any extent, there being a great abundance of wood, and at low prices; indeed the forests are computed to cover more than a third part of the productive soil of the empire, viz. 43,896,637 acres, therefore until these are reduced the extension of coal-mining cannot be expected.

The foregoing are the principal coal districts of our globe; there are however large tracts existing in many other portions of it. Spain, Portugal*, Lombardy, the Tyrol, Hungary, all yield coal. In *Bohemia* coal is abundant: the bituminous coal of Western Bohemia is particularly good and plentiful: the basin of Rakonitz is forty English miles from east to west, and from north to south is ten to twelve miles.

The coal-mine of Entreveines, near Annecy, in the *Duchy of Savoy*, furnishes a highly bituminous coal, which is exclusively used for the gas-lights in the cotton-mills of Annecy.

Poland contains several coal-areas: in some parts coal supplies the place of wood fuel, but the mining has been greatly neglected.

Sweden possesses several mines of an inferior kind of bituminous coal, but they

* An advertisement appeared in the 'Times' of August 27, 1852, requesting tenders for the supply of English coal for the Lisbon gas-works, the contract to be in force for a considerable number of years. At present, although coal exists and is mined at Peniche, the supply is limited and the price great; but it is paying surely a poor compliment to native industry to suppose that such a state of things will exist for *many years*.

are worked only to a limited extent, and she depends upon importations from England for good coal.

In *Russia*, on the northern shore of the Black Sea, bituminous coal (brown) has been found in abundance. The richest Russian coal-field is on the shores of the Sea of Azoff, between the Dnieper and Donetz rivers: it is said to be equal in quality to the best English, and may be delivered at a port on the Dnieper or the Don rivers for about 4*s*. or 5*s*. per ton. Little is known of the carboniferous system of Northern Russia. St. Petersburg is lighted with gas produced from English coal.

No bituminous coal has been found in *Norway*. *Holland* is also entirely destitute of this mineral.

In noticing the coal-producing areas of Europe and America, a few remarks may be made upon those of Africa and Asia. A gas-maker must not look only at home: notwithstanding the vast increase of his field of labour, the science, and the results of the science, are still in their young infancy. New districts are gradually raising up new towns, which increase and multiply, and will require his skill to give them artificial light; and although this may not eventually be produced by coal-gas, we know as yet of no other substance that can be brought commercially into competition with it: we must therefore study the coal-districts of the entire globe, and look to the future. The word ADVANCE is one too little attended to in the gas world. Prejudice surrounds the minds of many as with a thick fog, and improvements in the science are looked upon with jealousy and mistrust. Improvements, which cheapen the cost of production, affect the conservancy of old establishments, which have to pay interest upon uselessly expended capital; and any method of making gas which will involve a change, however slight, in their apparatus, and consequently a still greater outlay of money, is considered as a matter of business, an innovation, a nuisance, and a thing to be strenuously fought against. This however is not the feeling of the age. Look upon any process which will effect a change with *mistrust*, if you please, until it is proved to be workable to profit; but look with *jealousy* upon none. Several of our processes for producing coal-gas are barbarous, distilling the coal *in bulk* being one; but we have not contrived, or at all events have not introduced, any process to change this mode of distillation: it will come, there cannot be a doubt, and all our manipulation is equally liable to be changed. We are yet babies in the art, and the least we can do is to *endeavour* to keep pace with the fast advancing science of the times, being sure that, if no error of *principle* is ad-

mitted, we cannot with our present knowledge, although it *be* small, go very far wrong in practice. Be prudent; carefully weigh the merits and demerits of all "*new-fangled things;*" but accept the word ADVANCE with a different spirit from that of jealousy.

In 1844 a search was made for coal in *Egypt*, and it is stated that several beds were discovered in the oasis of Ghenne, on the Arabian side of the Thebaid. Several loads of coal arrived at Syout, in the spring of 1846, from the desert on their way to the lower province, whither they were sent for the Pasha's examination: this coal is stated to resemble the Scotch, and the discovery, should it prove as represented, will have some influence in the extension of gas-lighting. In tropical Africa, Major Sir W. C. Harris, an authority in every way entitled to credit, states that coal-beds appeared to extend along the whole of the eastern frontier of Shoa; the same officer also says that coal is found near the coast of Abyssinia. Coal is said to exist in Madagascar, in Mozambique, at Port Natal, and about 500 miles east of Cape Town, and there is every reason to think the report correct.

Asia is rich in her deposits of bitumen and other hydro-carbonaceous substances; there is also good reason to believe that coal exists extensively, and will be worked to profit in due time. At Erekli, in Anatolia, about 150 miles east of Constantinople, on the south shore of the Black Sea, is a formation, according to good authority, of genuine bituminous coal: it is said to be of considerable extent, of excellent quality, and situated so as to be easily transported. One hundred parts consist of*

Carbon	62·40
Volatile matter	31·80
Earthy matter	5·80

The Syrian coal, although rich in bitumen, abounds in sulphur, and converts all iron in contact with it at a red heat into a sulphuret; it is consequently unfit for commercial purposes.

Sir Alexander Burnes states that large districts of bituminous coal exist in *Cabul*, situated favourably for transport. Coal has long been well known in *Tartary*, where its use is not only mentioned by Marco Polo, but by many early writers. Much coal is also mined in *Japan*, but no particulars have been published.

Indigenous coal of the bituminous species has already been discovered in more

* Professor Hitchcock, in Transactions of the Association of American Geologists and Naturalists, 1843, vol. i. p. 392.

than one hundred localities in *Hindostan*, the best being that of the Narbudda and Burdwan districts, and the region above Sylhet. No mines have been opened,—at all events, none of sufficient importance to cause these districts to rank as coal-producing countries; but steam navigation *must*, in process of time, force them into work; for an enormous price may be afforded for the coal, since the freight of it from England is 40*s*. per ton, presuming always that there *does* exist a body of coal, for until it is fairly mined doubts must exist. In Bengal however it appears that mining has been sufficiently carried on to render the existence of workable coal pretty certain.

China, if we look very far into the future, will unquestionably become a coal-producing country. We have evidence that, amongst other varieties, there exists tertiary or brown coal, bituminous coal of various kinds, cannel coal, and anthracite, all of which have for ages been in common use in this remarkable country.

Whether the Chinese have adopted the principle of lighting their houses or towns with coal-gas, artificially produced from bituminous coal, we know not; but it is certain that there are gaseous exhalations, or natural vents from the earth, as well as numerous others which have been artificially produced, and which have been burning for centuries, and are turned to economical account.

A contributor to the 'Edinburgh Philosophical Journal' furnishes some details, whereby we ascertain that, if the Chinese are not *manufacturers* of gas, they are nevertheless gas employers and consumers on a large scale, and evidently were so ages before the knowledge of its application was acquired by Europeans. The process is the following:—Beds of coal, though at a great depth, are frequently pierced by the borers for *salt water*, and from the wells thus made the inflammable vapour springs up. It sometimes appears a jet of fire, from twenty to thirty feet high; and in the neighbourhood of Thsee-Licon-Tcing the salt-works were formerly heated and lighted by means of these fountains of fire. Bamboo-pipes carry the gas from the spring to the place where it is intended to be consumed; these tubes are terminated by other tubes of pipe-clay to prevent their being burnt; a single well heats more than three hundred kettles: the fire thus obtained is said to be so exceedingly brisk that the cauldrons are rendered useless in a few months. We presume this process refers to the boiling and evaporation of salt in the pans or kettles, through the agency of fire thus acquired from the ignition of the gas. For the purpose of illumination, other bamboo-tubes conduct the gas intended for lighting the streets, and into large apartments and kitchens; thus nature presents in these positions a complete establishment of gas-light works.

Australia is rich in other mineral products besides *gold*. At Newcastle and the Hunter region of New South Wales bituminous coal is ascertained to be abundant. Sydney is (or will be) supplied with coal from Lake Macquarrie: the Australian Agricultural Company sold 27,000 tons from thence in 1840. In South Australia the existence of coal has been reported, but has not been verified. In Western Australia no coal has been found.

Coal is stated to be traceable quite across the island of Van Diemen's Land.

On the shores of Evans Bay, near Port Nicholson, in the northern island of New Zealand, indications of coal have been found; and were they followed up, it is reasonable to suppose that they would lead to productive seams, as it exists in many places about Cook's Straits in great quantities. At Port Nelson also coal has been discovered, and in 1847 was used on board H.M.S. Inflexible at Auckland.

Nature has given coal to many other portions of the globe besides those mentioned, but space will not permit of more particular notice; enough probably has been said to show that gas-lighting will not be confined to narrow limits, but, on the contrary, will spread universally.

The most valuable information with respect to coal that can be given to the gas-engineer is, of course, the commercial worth of the various kinds for the production of illuminating gas; this information is also the most difficult to convey with certainty, the per-centage of volatile matter being the nearest criterion. The appearance of any coal, or its known quality as a *fat bituminous* and *blazing* coal, will not enable us to judge of it with anything like sufficient certainty to justify us in its use for commercial gas purposes; direct and careful experiment is advised in every instance. It is very true that a *dry* coal, or an *anthracite*, may be disregarded at once, but further than this an opinion formed upon inspection must not be hazarded. The quantity of gaseous matter yielded by any coal being, as before observed, the surest guide (even more sure than ultimate analysis), the following table is given, showing the volatile and carbonaceous products of the most valuable kinds:—

CANNELS AND BITUMINOUS COALS OF BRITAIN.	Analysis of 100 Parts of Coal.		
	Carbon.	Bitumen, Volatile Matter, and Water.	Ashes and Cinders.
Boghead	9·25	69·00	21·75
Lismahago Cannel	39·43	56·57	4·00
Newcastle (Ramsey's)	—	—	—
Newcastle, Birtley	60·50	35·50	4·00
Wigan Cannel	52·60	44·00	3·40
Lancashire Cannel (general average)	56·00	38·50	5·50
Northumberland Tyne Works	67·50	30·00	2·50
Derbyshire Cannel, Moreley Park	45·00	45·05	9·95
„ Cannel, Alfreton	55·27	40·73	4·00
„ Codnor Park, soft coal	51·50	45·50	3·00
„ Butterley, Cherry	57·00	40·00	3·00
„ Kirby Main coal	64·15	33·85	2·00
„ Dunshill, near Swanwick	55·77	40·73	3·50
„ Swanwick Main coal	60·27	38·23	1·50
„ Main upper hard, Duckmanton	64·47	32·03	3·50
„ Normanlow Corn, Codnor Park coal ...	56·21	41·66	2·13
„ Main soft coal	56·49	37·76	5·75
„ Alfreton Works, lower hard coal	62·60	35·15	2·25
„ Butterley Park Colliery	61·14	34·11	4·75
„ Moreley Park Works	55·89	37·86	6·25
„ Chesterfield	61·65	35·10	3·25
„ Double or Minge coal	60·66	37·34	2·00
„ Clod coal	61·21	37·29	1·50
„ Buckland Hollow or Kilburn coal ...	58·62	40·00	1·38
Yorkshire, Low Moor, better bed	67·06	32·19	0·75
„ Low Moor, black bed	71·42	27·08	1·50
„ Bowling, better bed	64·25	32·55	2·00
„ Bowling, Crow coal	66·15	33·85	1·00
„ Parkgate, Main coal	67·14	30·73	2·13
„ Old Parkgate vein	65·09	33·28	1·63
„ Parkgate, top coal, upper part of seven feet coal	62·51	36·49	1·00
„ Parkgate, bottom part	66·94	31·56	1·50
„ Birkenshaw coal	64·96	32·54	2·50
„ Worsborough furnace coal	60·32	38·18	1·50
„ Another specimen	56·45	40·85	2·50
„ Milton Main coal, splint part	69·40	27·60	3·00
„ Milton Main coal, roof or soft part ...	62·71	36·04	1·25
„ Thorncliffe, thin furnace coal	63·98	35·52	0·50
„ Smithy Wood coal	54·60	44·27	1·13
„ Easley Park	69·12	30·00	0·83
„ Yorkshire Kent coal	66·40	32·72	0·88
„ Strafford, main coal, five feet, bottom part ...	62·08	35·67	2·25
„ Strafford, main coal, top part	68·12	30·20	1·68
„ Silkstone, main coal	65·08	32·29	2·63
„ Silkstone, soft or clod coal	63·10	35·15	1·75

CANNELS AND BITUMINOUS COALS OF BRITAIN.	Analysis of 100 Parts of Coal. Carbon.	Bitumen, Volatile Matter, and Water.	Ashes or Cinders.
Forest of Dean, Gloucestershire, Cinderford furnace or lower High-coal Delf	62·00	36·00	2·00
" Park-end coal, Coleford High Delf, top	63·72	32·03	4·25
" Park-end coal, middle part	63·61	34·89	1·50
" Park-end coal, bottom part	60·96	37·29	1·75
" Church Way coal, top	60·33	35·67	4·00
" Church Way coal, bottom	64·13	34·74	1·23
" Rocky vein	61·73	36·14	2·13
" Starkey coal	61·53	36·72	1·75
" Park-end, Little Delf	58·15	36·35	5·50
" Park-end, Smith-end	63·36	34·89	1·75
Staffordshire, Corbyn's Hall, Tow coal, part of ten-yard coal	51·90	40·60	7·50
" Corbyn's Hall, Heathing coal	54·17	43·33	2·50
" Corbyn's Hall, Brooch coal	50·49	47·76	1·75
South Staffordshire, New Mine, top coal	52·77	45·10	2·13
" Fire Clay coal	51·40	46·35	2·25
" New Main, bottom coal	53·98	44·27	1·75
" Bentley Estate, Ten-yard coal ...	54·05	42·70	3·25
" Bentley Estate, Ten-yard coal, bottom part	63·57	34·18	2·28
" Bentley Estate, Four Feet coal ...	53·18	44·82	2·00
" Bentley Estate, Three Feet coal ...	54·82	43·12	2·00
" Bentley Estate, Fire Clay coal ..	54·84	42·91	2·25
" Bentley Estate, Bottom vein	62·87	32·00	5·12
" Bentley Estate, Five Feet Splint coal	49·42	45·83	4·75
" Bentley Estate, Bottom coal	79·78	10·72	9·50
North Staffordshire, Lane-end, Bassey Mine	58·30	38·70	3·00
" Lane-end, Little Mine	62·30	35·20	2·50
" Lane-end, Great Row coal ...	57·38	39·74	2·88
" Lane-end, Best Furnace coal	65·20	32·30	2·50
" Lane-end, Ashes coal	61·32	37·18	1·50
" Kidsgrove, Little Row coal	63·08	34·67	2·25
" Kidsgrove, Seven Feet coal ...	67·90	30·47	1·63
" Kidsgrove, Stony Vein	65·17	33·33	1·50
" Kidsgrove, Banbury or Harecas ...	63·84	35·16	1·00
" Kidsgrove, Knowles's coal, Delph Lane	59·64	37·86	2·50
" Kidsgrove, Peacock coal, Fenton Park	60·42	37·08	2·50
" Golden Hall, Spendcroft Vein ...	58·67	39·58	1·75
" Golden Hall, Ten Feet coal ...	58·89	39·11	2·00
" Golden Hall, Great Row coal ...	60·80	37·70	1·75
" Golden Hall, Little Row coal ...	62·47	34·53	3·00
Shropshire, Stone coal	58·17	39·20	2·63
" Sulphur coal	55·72	42·03	2·25
" Clod coal	63·79	35·58	1·63
" Randle coal	64·19	32·81	3·00
" Flint coal	60·63	36·87	2·50
" Top coal	64·10	34·77	1·13

CANNELS AND BITUMINOUS COALS OF BRITAIN.	Analysis of 100 Parts of Coal.		
	Carbon.	Bitumen, Volatile Matter, and Water.	Ashes or Cinders.
Shropshire, Best fungous coal	63·33	35·67	1·00
,, Doublo coal	57·87	41·38	0·75
Scotland, Clyde, upper vein, top	37·00	41·50	21·50
,, Clyde, upper vein, bottom	53·45	44·80	1·75
,, Clyde, second vein	42·10	48·34	9·56
,, Clyde, third or furnace	51·20	45·50	3·30
,, Clyde, fifth splint coal	53·40	42·40	4·20
,, Clyde, splint coal	59·00	36·80	4·20
,, Clyde, clod coal	70·00	26·50	4·50
,, Clyde, soft coal	42·25	47·75	10·00
,, Clyde, near Glasgow	64·40	31·00	4·60
,, Calder, furnace coal, top	49·98	43·82	6·20
,, Calder, furnaco, splint part	50·67	47·48	1·85
,, Calder, furnace, main coal, top	49·60	49·39	1·01
,, Calder, furnace, middle	52·30	39·95	7·75
,, Calder, furnace, bottom	51·60	44·51	3·89
,, Calder, near Glasgow	51·00	45·00	4·00
,, Monkland, near Glasgow	56·20	42·40	1·40
,, Middlerig	50·50	42·00	7·50
,, Glen Buck, furnace coal	53·20	45·20	1·60
,, Glen Buck, inferior	48·80	44·20	7·00
,, Cleugh, furnace coal	47·08	42·25	10·67
,, Marystone Pyat, show coal, top	49·60	49·31	1·09
,, Marystone Pyat, pine splint	51·82	46·57	1·61
,, Marystono Pyat, heavy splint	54·67	39·25	6·08
,, Govan coal, first vein, top part	49·55	44·65	5·80
,, Govan coal, first vein, lower part	49·41	48·92	1·67
,, Govan coal, second vein	48·20	48·34	9·46
,, Govan coal, fifth vein, splint	48·84	49·79	1·37
,, Govan coal, sixth vein, lower main	—	—	—
,, 1. Craw coal	51·58	44·60	3·82
,, 2. Head coal	48·08	49·38	2·54
,, 3. Ground coal	45·57	51·00	3·43
,, 4. Foot coal	52·27	44·15	3·58
Ireland, Kilkenny Cannel	74·47	25·01	0·50
North Wales, Brymbo coal, Three-yard coal, part not coked	61·31	38·80	2·89
,, Brymbo coal, Three-yard coal, part coked ...	62·70	35·70	1·60
,, Brymbo coal, Two-yard coal, coked ...	69·98	28·60	1·42
,, Brymbo coal, Brassy vein, cokod	64·58	34·10	1·32
,, Brymbo coal, Crank coal	73·56	25·70	0·74
,, Brymbo coal, Drowsall vein	62·69	36·70	0·60
,, Brymbo coal, Powell vein	63·41	34·80	1·79
,, Deo Bank, Five-yard vein, top part	61·89	36·20	1·91

CANNELS AND BITUMINOUS COALS OF BRITAIN.	Analysis of 100 Parts of Coal. Carbon.	Bitumen, Volatile Matter, and Water.	Ashes or Cinders.
North Wales, Dee Bank, Five-yard vein, middle ...	62·72	36·00	1·28
„ Dee Bank, Five-yard vein, bottom	63·79	32·85	3·36
„ Dee Bank, Three-yard coal	62·88	36·00	1·12
„ Dee Bank, Two-yard coal	60·61	38·47	0·92
„ Dee Bank, Bone coal	55·20	40·00	4·80
„ Pankey Iron Works, stone vein	61·95	35·67	2·38
„ Pant Iron Works, blast furnace coal ...	67·25	31·25	1·50
„ Coed Talon, blast furnace coal	58·50	40·00	1·50
„ Sweeny Colliery, brassy vein	49·94	34·56	15·50
„ Cefn Colliery, near Rhuabon Works ...	57·49	36·56	6·25
„ Cefn Colliery, Brassy coal	66·37	32·13	1·50
„ Black Park coal, Two-yard vein	57·50	40·00	2·50
„ Black Park coal, One-and-a-half-yard vein	59·88	38·23	2·00
„ Llwyn-y-onnion, Half-yard coal	62·85	34·40	2·75
„ Chirke Bank Colliery, Strangers' coal ...	57·00	40·00	3·00
„ Delf Colliery, Yard coal, near Rhuabon ...	64·89	34·11	1·00
South Wales—*Eastern side of Coal Basin.*			
„ Abersychan, Meadow vein	65·98	29·40	4·62
„ Abersychan, Old coal	71·10	27·40	2·50
„ Golynos Iron Works, Three-quarter	71·88	25·50	2·62
„ Golynos Iron Works, Rock vein ...	69·60	27·40	3·00
„ Golynos Iron Works, Meadow vein ...	68·00	27·50	4·53
„ Verteg Iron Works, Red vein	69·45	26·30	4·25
„ Verteg Iron Works, Big vein	66·05	30·70	3·25
„ Verteg Iron Works, Droydeg and Rock vein	64·45	32·30	3·25
„ Verteg Iron Works, Three-quarter	67·90	29·60	2·50
„ Verteg Iron Works, Meadow vein ...	69·25	30·50	9·25
„ Blaenafon Iron Works, Three-quarter ...	65·63	31·25	3·12
„ Blaenafon Iron Works, Droydeg and Rock vein	65·55	28·95	5·50
„ Blaenafon Iron Works, Meadow vein ...	72·00	26·00	2·00
„ Llanelly Iron Works, Three-quarter ...	72·70	25·30	2·00
„ Llanelly Iron Works, Tach coal	70·05	25·57	4·38
„ Blaina, Big vein	72·14	25·86	2·00
„ —*South-eastern side of Coal Basin.*			
„ Mynyddyslwyn vein, Powell's	66·58	27·92	5·50
„ Mynyddyslwyn vein, Morrison's ...	68·58	36·92	4·50
„ Mynyddyslwyn vein, Penner vein	60·25	33·00	6·75
„ Mynyddyslwyn vein, Cwm Dows (Morrison)	68·86	27·14	4·00
„ Mynyddyslwyn vein, Prothero's ...	64·95	33·30	1·75
„ Mynyddyslwyn vein, Roper Williams ...	68·50	30·00	1·50
„ Beddws vein, Phelps's	68·00	30·00	2·00
„ Beddws vein, Abercarne	66·88	28·37	4·75
„ Beddws vein, Cwm Carne	62·63	31·10	6·25
„ Risca veins, Upper Rock vein	66·11	31·14	2·75
„ Risca veins, Lower Rock vein	61·78	34·28	3·94
„ Risca veins, Big vein	66·02	29·15	2·83

CANNELS AND BITUMINOUS COALS OF BRITAIN.	Analysis of 100 Parts of Coal.		
	Carbon.	Bitumen, Volatile Matter, and Water.	Ashes or Cinders.
South Wales, Risca veins, Red vein	61·25	33·80	4·95
" Risca veins, Sun vein or Meadow vein ...	67·28	31·34	1·38
" Cwm Brane coals, Yard vein	63·03	32·60	4·37
" Cwm Brane coals, Rock vein	62·22	34·78	3·00
" Cwm Brane coals, Red vein	60·65	31·35	8·00
" Cwm Brane coals, Meadow vein	66·34	28·16	5·50
" Cwm Brane coals, Old coal	68·30	27·70	4·00
" Blaen-dare Furnace coal, Rock vein ...	68·86	28·64	2·50
" Blaen-dare Furnace coal, Meadow vein ...	67·84	29·16	3·00
" Pen Twyn Furnace coal, Big vein	71·88	25·50	2·62
" Pen Twyn Furnace coal, Meadow vein ...	53·65	32·60	3·75
" Pen Twyn Furnace coal, Old coal	68·50	27·50	4·00
" Abersychan British Iron Company, Red vein	72·95	25·30	1·75
" Abersychan British Iron Company, Big vein	67·05	25·70	7·25
" Abersychan British Iron Company, Rock vein	69·30	25·70	5·00
" —*South side of the Coal Basin.*			
" Park, south veins of this basin between Pyle and Llantrissant, Cribbwr Vach	72·36	26·14	1·50
" Park, south veins of this basin between Pyle and Llantrissant, Bedws vein	70·68	25·82	3·50
" Park, south veins of this basin between Pyle and Llantrissant, Llangonydd	60·40	38·60	1·00
" Park, south veins of this basin between Pyle and Llantrissant, Llangonydd, No. 2	69·64	27·86	2·50
" Park, south veins of this basin between Pyle and Llantrissant, Llangonydd, Twenty-inch	70·22	28·28	1·50
" Park, south veins of this basin between Pyle and Llantrissant, Herwain, common	69·34	29·16	1·50
" Park, south veins of this basin between Pyle and Llantrissant, Llanharry	65·75	33·00	1·25
" Park, south veins of this basin between Pyle and Llantrissant, Collenna, Three feet ...	75·06	23·44	1·50
" Park, south veins of this basin between Pyle and Llantrissant, Collenna, Cannel ...	63·25	34·12	2·63
" Mellin Criffin and Pentyrch, near Cardiff, Little vein	70·66	27·34	2·00
" Mellin Criffin and Pentyrch, near Cardiff, Brassy vein	61·00	30·00	9·00
" Mellin Criffin and Pentyrch, near Cardiff, Pentyrch Forked vein	64·63	31·87	4·50

In many of the collieries of South Wales there are veins of semi-bituminous and anthracitic coal alternating with the richer gas-coal; where their per-centage of

volatile matter has fallen below 25·00, they have been omitted in the tables: it is true that some coal with a still lower per-centage is used for the production of gas, but even 25·00 is too low for the coal to be profitably employed,—at all events, it is the limit; below this per-centage, until it becomes anthracite, the coal may be fairly classed with the semi-bituminous. Anthracite yields at most twelve per cent. of volatile matter, and the purest about two per cent.

TABLES OF ANALYSIS OF AMERICAN BITUMINOUS COAL*.

State and County.	Locality.	Designation of Coal Beds.	By whom Analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
KENTUCKY	Hawsville	Splint or Cannel coal	Dr. Jackson	1·250	48·40	4·80	2·80
	Caseyville	Bituminous coal	Johnson	1·392	44·49	3·82	23·69

Fat Bituminous Coals in Western Virginia.—State Reports.

County.	Locality.	Designation of Coal Beds.	Analysis.		
			Carbon.	Volatile Matter.	Ashes.
[Upper Coal Series.]	Clarksburg	Main seams	56·74	41·66	1·60
	,,	,,	49·21	45·43	5·36
	Pruntytown	,,	57·60	39·00	3·40
	Morgantown	,,	60·54	37·30	2·14
Lower Coals—Valley of the Ohio. Kanawha	1, Coal Creek	Judge Summers's Bank	55·55	41·85	2·60
,,	2, Grand Creek	,,	52·75	43·20	4·05
Logan	3, Wolf Creek, Big Sandy River	Burning Spring	47·15	48·00	4·85
Kanawha	4, Big Coal River	(Lewis's)	50·20	47·10	2·70
,,	5, Three-mile Creek	Cartrell's	45·95	50·30	3·75
,,	6, Elk River	Friend's Mines	55·90	39·90	5·20
Logan,	7, Logan Court-house	Lawson's	58·35	39·50	2·15
,,	8, Guyandotte	Traa Fork	56·50	42·00	1·50
,,	9, Big Sandy River	Pigeon Creek	55·00	41·00	4·00

* The Analytical Tables here given are compiled from a comprehensive series of "about Eleven Hundred Species of Mineral Combustibles, disposed in Geographical Order," appended to Mr. R. C. Taylor's valuable work on the "Statistics of Coal," to which the attention of our readers has been before directed.

Moderately Bituminous Coals in Western Virginia.

	County.	Locality.	Designation of Coal Beds.	By whom Analysed.	Analysis. Carbon.	Volatile Matter.	Ashes.
Lower Coal Series in the Valley of the Kanawha. Formation No. XI., Rogers.	Fayette	Big Sewell Mountain, W. flank	Tyree's bed	Wm. B. Rogers	67·84	30·08	2·08
		,,	Deem's bed	,,	71·73	27·13	1·14
		Mill Creek	Paris's bank	,,	71·88	26·20	1·92
		Scrabble Creek		,,	63·36	29·04	7·60
		Bell Creek		,,		32·16	
		Keller's Creek	Hansford's	Wm. B. Rogers's State Report	60·92	37·08	2·00
		Second seam	Storkton's mine	,,	74·55	21·13	4·32
		Campbell's Creek	Ruffner's 2nd seam	,,	55·76	32·44	11·80
		,,	Noyes's seam	,,	64·16	32·24	3·60
		,,	,,	,,	65·64	31·28	3·08
		Cox's Creek	3rd seam	,,	51·41	42·55	6·04
		Faure's Bank	Upper seam	,,	53·20	35·04	11·76
		L. Ruffner's Bank	,,	,,	49·84	44·28	5·88
		Bream's Bank	3rd seam	,,	57·76	33·68	8·56
		Smither's Bank		,,	54·52	29·76	15·76
		Hughes's Bank		,,	62·32	32·88	4·80
		D. Ruffner's Bank	Upper seam	,,	57·28	35·08	7·64
		Warth's Bank		,,	54·00	39·76	6·24
WESTERN VIRGINIA. *Preston and Mongalia Counties.—Basins containing the Lower Coal Series.*	Preston	Kingswood	Fairfax's	State Reports	53·77	31·75	14·48
	,,	,,	Middle seam		65·32	27·77	6·91
	,,	,,	Forman's basin		73·68	21·00	5·32
	,,	Deck Hollow, c.	Martin's		65·42	23·42	11·16
	,,	Buffalo Leech run	Beatty's		62·56	29·60	7·84
	,,	N. Brandonville	Morton's		65·28	30·80	3·92
	,,	Cheat River, near Kingswood	Price's		60·36	25·00	14·64
	,,	Big Sandy, W. side	Seaport's		66·64	27·12	6·24
	,,	Kingswood	Hagan's		68·32	26·48	5·20
	,,	,,			67·28	29·68	3·04
	,,	Big Sandy Basin	W. side Cheat		60·04	26·88	13·08
	,,	Kingswood	Cresaps		64·24	30·24	5·32
Bituminous Coals in EASTERN VIRGINIA, *in the Chesterfield, Powhatan, Goochland, and Henrico Basins.*	South side of James River 1	Stonehenge	Chesterfield		58·70	36·50	4·80
	Chesterfield 2	Maidenhead	Engine shaft		63·97	32·83	3·20
	,, 3	Heth's Pit	,,		62·35	37·65	2·80
	,, 4	Mill's and Reid's	Creek pit		57·80	38·60	3·60
	,, 5	Will's Pit			62·90	32·50	4·60
	,, 6		Green-hole shaft		67·83	30·17	2·00
	,, 7	Heth's Deep Shaft	Bottom seam		53·36	35·82	10·82
		,,	Middle seam		66·50	28·40	5·10
		,,	Top seam		61·68	28·80	9·52
	,, 8	Powhatan Pits	Finney		59·87	32·33	7·80
	,, 9	Winterpock Creek	Cox's mine		65·52	29·12	5·36
		Cloverhill, Appomattox R.	Slate coal	G. W. Andrews, M.D.	55·00	38·50	6·50
		,,	Mean of 4 species	Johnson	54·83	33·04	10·13

County.	Locality.	Designation of Coal Beds.	By whom Analysed.	Analysis.		
				Carbon.	Volatile Matter.	Ashes.
Bituminous Coals in EASTERN VIRGINIA—*continued.*	Richmond coal		Andrews	59·25	32·00	8·75
	Mid Lothian	Wooldridge's pit	Johnson	61·08	28·45	10·47
	,,	Mean result, average size coal	,,	53·01	33·25	14·74
	Creek Coal Co.	Mean of six trials	,,	60·30	31·13	8·57
	Black Heath Pits	Mean of 4 species	,,	58·79	32·57	8·64
	Tippecanoe Pits	,,	,,	54·62	36·01	9·37
North side of James R. 10		Randolph's	W. B. Rogers, State Report	66·15	30·50	3·35
11	Coalbrook Dale	Second Seam	,,	66·48	29·00	4·52
12	Anderson's Pit	First seam	,,	66·78	28·30	4·92
17	Crouche's Lower Shaft	Upper seam, 110 ft. from surface	,,	64·60	30·00	5·40
18	Scott's Pit		Johnson, State Report	60·86	33·70	5·44
19	Waterloo Shaft		,,	55·20	26·80	18·00
20	Deep Run Pits		,,	69·84	25·16	5·00
	Wills's Pit	Upper vein	T. G. Clemson }	66·60	28·80	4·60
	Anderson's Pit	Bottom seam	R. C. Taylor }	64·20	26·00	9·80

Fat Bituminous Coals in the State of Ohio.

County.	Locality.	Designation of Coal Beds.	By whom Analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Portland	Talmadge	Upson's mine	W. W. Mather	1·264	53·404	44·298	2·288
Jackson	Lick Township		,,	1·283	49·882	47·327	2·221
,,	Madison Township		J. L. Cassels	1·560	39·950	44·800	14·620
,,	,,	Cannel coal	,,	1·410			
	Carr's Run		R. C. T.	1·270			
	Pomeroy		Dr. J. Percy		76·70	18·70	4·60

Fat Bituminous Coals in Pennsylvania.

County.	Locality.	Names of Coal Seams.	By whom Analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Venango	Shippensville	Sandy Ridge	H. D. Rogers's State Report		49·80	43·20	7·00
,,	6. M. F. of Franklin		,,		29·54	52·78	17·68
Beaver	Greersburg		,,		30·12	36·00	33·88
Crawford	Conneaut Lake		,,		59·45	38·75	1·80
Mercer	Greensville		,,		57·80	40·50	1·70
	,,		R. C. T.	1·25			
	Orangeville		State Report		53·45	43·75	2·80

Bituminous Coals.

State and County.	Locality.	Designation of Coal Beds.	By whom Analysed.	Specific Gravity.	Analysis. Carbon.	Volatile Matter.	Ashes.
INDIANA.							
Vermillion	Brouillet's Creek		D. D. Owen	1·270	52·00	39·00	9·00
Vigo	Honey Creek		,,	1·240	70·00	27·50	2·50
Sullivan	Busseron	Lick Fork	,,	1·240	70·00	28·00	2·00
Fountain	Wabash	Coal-creek mouth	,,	1·260	60·00	25·00	15·00
Spencer	Anderson Creek		,,	1·270	45·00		
	White River		,,	1·270	56·40		
	Terre Haute		,,	1·240	50·80		
	Cannelton	Cannel coal	W. R. Johnson	1·272	59·47	36·59	3·94
ILLINOIS	Rock River	Coal	Dr. D. D. Owen	1·340	45·50	44·50	10·00
	Vermillion	Danville	A. Morfit		48·50	47·20	4·30
	Western Port		Johnson	1·290		32·80	
	Ottowa		J. F. Frazer		62·60	35·50	1·90
	Rockwell		C. U. Sheppard	1·273	46·50	47·50	6·00
IOWA	Duck Creek	West bank of the Mississippi R.	Dr. D. D. Owen	1·270	48·50	44·00	7·50
		Mastodon vein, 46 feet thick	Booth and Boye		46·83	40·05	13·12
			J. R. Chilton, MD.	1·252	50·81	34·06	15·13
MISSOURI	Côte sans dessein, Callaway co.	Mammoth vein, 24 feet	,,	1·250	50·78	34·20	15·02
	Osage River		W. R. Johnson	1·200	51·16	43·50	5·34
ARKANSAS	Johnson county	Spaldre's bluff	J. F. Frazer	1·396	62·60	28·90	8·50
MAINE		Peat	Dr. Jackson		21·00	72·00	7·00
Miscellaneous Analysis.							
Isle of Cuba	Near Havana	Asphaltum	T. G. Clemson	1·190	34·97	63·00	2·03
	Near Matanzas	Asphaltum	,,				13·50
South America	Peru	Coxitambo	M. Bousingault				
	Chili	Arauco	W. R. Johnson	1·324	67·62	30·00	2·38
	Brazil		Karsten	1·289	57·90	40·50	1·60
	,,		,,	1·483	38·10	33·50	28·40
Madeira Island	Brown coal	Or lignite	Johnstone				20·05
British America, Bitum. Coal.							
Nova Scotia	Pictou	Cunard's sample	Johnson	1·325	60·73	26·76	12·51
		Mining Association	,,	1·318	56·98	29·63	13·39
Cape Breton	Sydney	Mean of 2 species	,,	1·338	67·57	26·93	5·50

Bituminous Coals in Belgium.

Countries, Provinces, and Varieties of Coal.	Locality.	Designation of Coal Beds.	By whom Analysed.	Specific Gravity.	Analysis.		
					Carbon.	Oxygen and Hydrogen.	Ashes.
Province of Hainault. Near Mons	Dour		Berthier		71·50	23·30	5·20
	”		”	1·307	88·00		2·50
	”		”		85·00	12·70	2·30
			M. Canchy	1·276	84·67	13·23	2·10
			”	1·292	83·87	12·47	2·68
	Basin of Mons	Plate seam	M. Chevalier	1·273			1·98
	”		”	1·263			1·27
	”		Karsten	1·307	85·50	12·00	2·50
	Canton of Dour		Berthier	1·270	71·50	23·30	5·20
	Near Mons	Bouleau	”	1·270	65·30	33·00	1·70
		Grand Gaillet	”		58·50	38·50	3·00
		Gade vein	”		51·00	44·00	5·00
Province of Liége.	Liége	St. Margarite	C. Davreux		78·30	17·80	3·90
			”		76·00	19·60	4·40
	”	Olisson	”		69·90	23·40	6·70
			”		72·60	24·20	3·20
	”	Cerisier	”		68·50	21·20	10·30
Dry Coals.	Harion	L'Harbe St. Michael	M. Delvaux	1·365	81·90	9·00	9·10
	Chokier	Petite Hareng	”	1·286	71·68	16·36	11·96
	Bonnier	Moset seam	”	1·318	91·38	8·00	6·12

Bituminous Coals in Germany.

Countries, Provinces, and Varieties of Coal.	Locality.	Designation of Coal Beds.	By whom Analysed.	Specific Gravity.	Analysis.		
					Carbon.	Oxygen and Hydrogen.	Ashes.
Upper and Lower Silesia	Waldenberg	Glanz coal	Richter		57·20	36·40	6·40
	Sabrze	”	”		63·20	32·93	3·90
	Bielschowitz	”	”		58·17	37·89	8·93
	Leopoldinengrube	”	Gay Lussac		61·50	35·62	2·88
	Friederich zu Zawada		Karsten	1·263	57·90	42·00	2·10
	Gustav Grube		”	1·270	68·00	30·10	1·90
Saxon States	Sälzer	Newark	”	1·288	81·60	17·70	0·70
”	”	”	Gay Lussac		80·10	18·90	1·00
Prussian Saxony	Circle of the Saale	Wettin or Wittenberg	Karsten	1·466	56·70	18·90	24·40
Germany	Brown coal	Shraplau			20·25	62·25	17·50
”	Eschweiler	Flotz Gyr	Gay Lussac		32·40	16·42	1·18
”		”	Karsten	1·300	80·23	18·60	1·17
Saxony	Pottschapel	Gate Schicht	”	1·454	41·00	31·30	27·70
”	Planitz	Pitch coal	”	1·860	63·40	35·50	1·10
Bohemia	Elbogen	Brown coal	M. Balling		37·18	56·16	6·66
”	Schlakenwerth	Carbonized peat	M. Debette		67·00	30·00	3·00
Würtemberg	Königsbrunn	Raw peat	M. Berthier		24·40	70·60	5·00

The following table gives the mean composition of some varieties of coal more or less suited for gas-making, which have not been before noticed. The value of a coal for gas purposes cannot be estimated with absolute certainty from a mere analysis, but generally speaking the value is *directly proportional to the number of atoms of hydrogen, and indirectly to the atoms of oxygen.* The relative number of atoms is seen by dividing the per-centage amount of each element by its atomic weight, thus:—

Wigan Cannel.

Carbon .... 6) 79·23 = 13·20 = number of atoms.
Hydrogen .... 1) 6·08 = 6·08 = „
Oxygen .... 8) 7·24 = 0·90 = „

Orrell Coal.

Carbon .... 6) 82·61 = 13·77 = number of atoms.
Hydrogen .... 1) 5·86 = 5·86 = „
Oxygen .... 8) 7·44 = 0·93 = „

The products of the distillation of a coal do not seem however to depend upon its per-centage composition, but upon the atomic arrangement of the elements which determine the quantity of hydrogen that unites with carbon to form illuminating compounds, and the quantity which escapes as free hydrogen or as light carburetted hydrogen, both of which have no illuminating power.

	LOCALITY OR NAME OF COAL.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Per-centage of Coke left by each Coal.
NEWCASTLE COALS.	Andrew's House (Tanfield)	85·58	5·31	4·39	1·26	1·32	2·14	65.13
NEWCASTLE COALS.	Willington	86·81	4·96	5·22	1·05	0·88	1·08	72.19
NEWCASTLE COALS.	Haswell Wallsend	83·47	6·68	8·17	1·42	0·06	0·20	62.70
NEWCASTLE COALS.	Haswell Coal Co.'s steam-boat Wallsend	83·71	5·30	2·79	1·06	1·21	5·93	61·38
NEWCASTLE COALS.	Bowden Close	84·92	4·53	6·66	0·96	0·65	2·28	69·69
NEWCASTLE COALS.	Broomhill	81·70	6·17	4·37	1·84	2·85	3·07	59·20
NEWCASTLE COALS.	Newcastle Hartley	81·81	5·50	2·58	1·28	1·69	7·14	64·61
NEWCASTLE COALS.	Hedley's Hartley	80·26	5·28	2·40	1·16	1·78	9·12	72·31
NEWCASTLE COALS.	Bates's West Hartley	80·61	5·26	6·51	1·52	1·85	4·25	72·31
NEWCASTLE COALS.	Buddle's West Hartley	80·75	5·04	7·86	1·46	1·04	3·85	72·31
NEWCASTLE COALS.	West Main Hartley	81·85	5·29	7·53	1·69	1·13	2·51	59·20
NEWCASTLE COALS.	Hastings's Hartley	82·24	5·42	6·44	1·61	1·35	2·94	35·60
NEWCASTLE COALS.	Carr's Hartley	79·83	5·11	7·86	1·17	0·82	5·21	60·63
NEWCASTLE COALS.	Davison's West Hartley	83·26	5·31	2·50	1·72	1·38	5·84	59·49
NEWCASTLE COALS.	North Percy Hartley	80·03	5·08	9·91	0·98	0·78	3·22	57·18
NEWCASTLE COALS.	Derwentwater Hartley	78·01	4·74	10·31	1·84	1·37	3·73	54·83
NEWCASTLE COALS.	Original Hartley*	81·18	5·56	8·03	0·72	1·44	3·07	58·22
NEWCASTLE COALS.	Cowpen and Sidney Hartley	82·20	5·10	7·97	1·69	0·71	2·33	58·59

* This colliery, situated about ten miles north-east of Newcastle and two miles from the port of Seaton Sluice, is one of the oldest in the district, and is that from which the Northumberland coal derives its name. The first five descriptions of coal are from the county of Durham.

	LOCALITY OR NAME OF COAL.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Per-centage of Coke left by each Coal.
LANCASHIRE COALS.	Balcarres Arley or Orrell	83·54	5·24	5·87	0·98	1·05	3·32	62·89
	Balcarres High Yard	82·26	5·47	5·64	1·25	1·48	3·90	66·09
	Balcarres Lindsay	83·90	5·66	5·53	1·40	1·51	2·00	57·84
	Balcarres Five Feet	74·21	5·03	8·69	0·77	2·09	9·21	55·90
	Blockley Hurst	82·01	5·55	5·28	1·68	1·43	4·05	57·84
	Blackbrook Little Delf	82·70	5·55	4·89	1·48	1·07	4·31	58·48
	Blackbrook Rushy Park	81·16	5·99	7·20	1·35	1·62	2·68	58·10
	Rushy Park Main	77·76	5·23	8·99	1·32	1·01	5·69	56·66
	Johnson and Wirthington's Rushy Park	79·5	5·15	9·24	1·21	2·71	2·19	57·52
	Laffak Rushy Park	80·47	5·72	8·33	1·27	1·39	2·82	56·26
	Ince Hall Co.'s Arley	82·61	5·86	7·44	1·76	0·80	1·53	64·00
	Ince Hall, Pemberton Yard	80·78	6·23	7·53	1·30	1·82	2·34	60·60
	Ince Hall, Pemberton Four Feet ...	77·01	3·93	5·52	1·40	1·05	1·09	57·10
	Ince Hall, Pemberton Five Feet ...	68·72	4·76	18·63	2·20	1·35	14·34	56·50
	Ince Hall Co.'s Furnace Vein ...	74·74	5·71	13·52	1·53	0·96	4·04	58·40
	Haydock Little Delf	79·71	5·16	10·65	0·54	0·52	3·42	58·10
	Haydock Higher Florida	77·33	5·56	12·02	1·01	1·03	3·05	51·10
	Moss Hall, Pemberton Four Feet ...	75·53	4·82	7·98	2·05	3·04	6·58	55·70
	Moss Hall, Pemberton Five Feet ...	76·16	5·35	10·13	1·29	1·05	6·02	56·10
	Moss Hall Co.'s New Mine	77·50	4·84	12·16	0·98	1·36	3·16	57·70
	King coal	73·66	5·30	9·06	1·68	1·58	8·72	62·40
	Caldwell and Thompson's Rushy Park ...	76·17	5·46	14·87	1·09	0·91	1·50	58·70
	Caldwell and Thompson's Higher Delf	75·40	4·83	19·98	1·41	2·43	5·95	54·20
	Johnson and Wirthington's Sir John ...	72·86	4·98	8·15	1·07	1·54	11·40	56·15
	Wigan Four Feet	78·86	5·29	9·57	0·86	1·19	4·23	60·00
	Wigan Cannel	79·23	6·08	7·24	1·18	1·43	4·84	60·33
SCOTCH COALS.	Dalkeith Jewel Seam	74·55	5·14	15·51	0·10	0·33	4·37	49·8
	Dalkeith Coronation Seam ...	76·94	5·20	14·37	Trace	0·38	3·10	53·5
	Wallsend Elgin	76·09	5·22	5·05	1·41	1·53	10·70	58·45
	Wellewood	81·36	6·28	6·37	1·53	1·57	2·89	59·15
	Kilmarnock Skerrington	79·82	5·82	11·31	0·94	0·86	1·25	49·3
	Fordel Splint	79·58	5·50	8·33	1·13	1·46	4·00	52·03
	Grangemouth	79·85	5·28	8·58	1·35	1·42	3·52	56·6
	Eglinton	80·08	6·50	8·05	1·55	1·38	2·44	54·94
ANTHRACITE		94·18	2·99	0·76	0·50	0·59	0·98	—
		91·44	3·46	2·58	0·21	0·79	1·52	92·90

The contrasted value of the two last descriptions of coal will serve as a guide to economic worth of the others.

List of Authorities.—Phillips and Conybeare, 'Geology of England and Wales.' Bridgewater Treatise, Buckland. D. Muchet on Iron and Steel. Official Catalogue of Exhibition, 1851. R. C. Taylor, 'Statistics of Coal.' 'Reports on Coal suited to the Steam Navy,' Sir H. De la Beche and Dr. Lyon Playfair.

The following report of Dr. Fyfe upon Boghead coal explains its value for gas-making:—

"I have submitted to analysis and examination the cargo of Boghead cannel coal sent to Aberdeen, with the view of ascertaining its value for the manufacture of gas; and I

have to report:—That the coal is of a brownish colour, with the exception of a few pieces, which are black. It is very hard. Its specific gravity is 1180 compared to that of water as 1000; a cubic foot of it therefore weighs 73 lbs.

"100 parts of the coal, by analysis, afforded, on an average:—

Volatile matter	69			
Coke	31	consisting of	Carbon, 9·25	=30 per cent.
			Ashes, 21·75	=70 „
	100		31·0	100

"The ashes consisted of 71 per cent. of silica: the remaining 32 per cent. consisted of lime, magnesia, alumina, and a minute quantity of iron, in union with sulphur. The percentage of sulphur amounted to 0·13, equivalent to nearly three pounds in the ton of coal.

"The quantity and quality of the gas afforded by carbonizing the coal, in the usual way, varied, but not much, according to the heat applied. The following is a tabular view of the results, taking the average of ten trials. The *durability* was ascertained by consuming the gas by a single jet, having an aperture of 1-33rd of an inch, and a flame of five inches in length. The *illuminating power* was determined by the use of the Bunsen Photometer, the gas being consumed by Argands, burning from 2½ to 3½ feet per hour, according to circumstances. The candle referred to was spermacceti, burning 140 grs. per hour, and proportioned, by calculation, to one burning 120 grs.:—

Cubic feet of Gas per ton of Coal.	Specific Gravity.	Conds. by Chlor. in 100 parts.	Durability; 1 foot burns		Illuminating power; 1 ft.=light of Candles		1 foot=grs. of Sperm.	Gas of 1 ton = lbs. of Sperm.	lbs. of Coke per ton of Coal.
			MIN.	SEC.	140 grs.	120 grs.			
15·486	726	23·37	84	44	8·9	10·38	1245·6	2755·6	760

"The quantity of sulphur, it has been already stated, was nearly 3 lbs. per ton. Supposing that the whole of it were given off in the state of sulphuretted hydrogen, when the coal is carbonized, the quantity afforded would amount to about 36 feet,—that is, about 2½ in the 1000 of coal-gas,—a quantity so extremely small as to be altogether unworthy of notice. Hence it is very easily removed by the common process of purification by lime. Accordingly, the coal-gas, when passed through the lime purifier, did not contain a trace of sulphur; it was also entirely free from carbonic acid, and from ammonia.

"With regard to the coke, it is very soft, and easily reduced to powder. From this circumstance, and from the small quantity of carbon it contains, I consider it of no value as a fuel.

"From the above, it is evident that the Boghead cannel coal is one of superior quality, compared to other coals now in general use for the manufacture of coal-gas. The following table shows the comparative value of the gases from some of these coals; also, the comparative value of the coals for affording light by the combustion of their gases. The English coal referred to in the table is that which is now used in some of the gas-works in

London, under the name of New Pelton and South Peareth coal. The value of Lesmahago coal is derived from the results of numerous trials which I have made with cargoes from different pits. The average of all the trials is given.

Coals.	Cubic feet of Gas per ton.	Illuminating power, 1 foot = light of Candles. 120 grs.	Comparative value of Gases, according to illuminating power.		Comp. value of Coals according to illuminating power & quantity of Gas afforded.	
Best English Caking	9,746	3·18	1·00		1·00	
Average Lesmahago	10,176	8·77	2·75	1·00	2·87	1·00
Average Boghead	15,486	10·39	3.25	1·18	5·17	1·77

Thus showing, by the photometer test, and taking the quantity of gas afforded by the coal into account, the Boghead cannel coal is upwards of four times more valuable than the English caking coal above mentioned, and 77 per cent. superior to the average of Lesmahago coal in the production of light by the combustion of their gases.

"The above is the value of the coals, and of their gases, as determined by the photometer test. When we have recourse to the chlorine test, the value of the Boghead coal becomes greater; owing, in addition to the large quantity of gas which it affords, to the greater durability of the gas, and to the amount of matter in it condensible by chlorine.

"The following table shows, by the chlorine test, the comparative value, not only of the coals above mentioned, but also of other kinds now in use in the manufacture of gas. In this comparative view, the quantity of gas afforded by the coals, the durability of the gases, and the amount of condensation by chlorine, are all taken into account.

Coals.	Cubic feet of Gas per ton.	Condensation by Chlorine in 100 parts.	Durability; with jet flame 5 inches 1 foot burns		Value of Gas, according to cond. by Chlor. and to durability.	Value of Coals, according to value and quantity of Gas.	Comp. value of Scotch Coals, only taking value and quantity of Gas into account.
			MIN.	SEC.			
English Caking	9,746	6·5	50	40	1·00	1·00	
English Parrot	10,500	7·6	44	30	1·02	1·08	
Marquis of Lothian's	10,000	13·0	60	0	2·35	2·41	1·00
Lesmahago	10,176	17·5	70	0	3·72	3·87	1·64
Wemyss	10,000	19·5	75	0	4·44	4·55	1·94
Kirkness	9,620	20·75	80	18	5·06	4·99	2·06
Boghead	15,486	23·37	84	22	6·09	9·67	4·01

"With regard to the difference between the value of the coals, as indicated by the photometer and by the chlorine test, I believe it to be owing to our not having yet acquired the proper method of burning advantageously the gases of very high illuminating power—such as those which, like the Boghead coal-gas, contain a large quantity of matter condensible by chlorine,—hence, in one respect, the value of the Boghead coal. It is valuable not only on account of the large quantity of gas which it affords, and for the high illuminating power of that gas, as indicated by the photometer; it will be found also to be extremely valuable from the large quantity of matter condensible by chlorine which it contains, and which is the principal source of light. Accordingly, were Boghead coal-gas

mixed with gas from inferior kinds of Parrot coal, and from English caking coal, it would add greatly to their illuminating power; or, which is the same, were the Boghead coal-gas diluted with gas from these inferior coals, while the quantity of gas would be increased, the illuminating power of the Boghead coal-gas, as indicated by the photometer, would, most probably, be very little diminished. I conceive therefore that the Boghead coal will be of great value to those using inferior kinds of coal in the manufacture of gas,—such as the poorer Scotch cannel coals, and especially the English caking coals.

"The above remarks regarding the comparative value of the coals referred to, apply solely to the quantity and quality of the gases they afford; they have no reference whatever to the coke, nor to the other products of distillation,—such as the tar and ammoniacal liquor. Of course, the coke of the Boghead coal being considered valueless as fuel, must detract from the value of that coal when compared in that respect with others which yield a valuable coke."

See also 'Journal of Gas Lighting' for January, 1851.

Experiments on the Products from Coal.

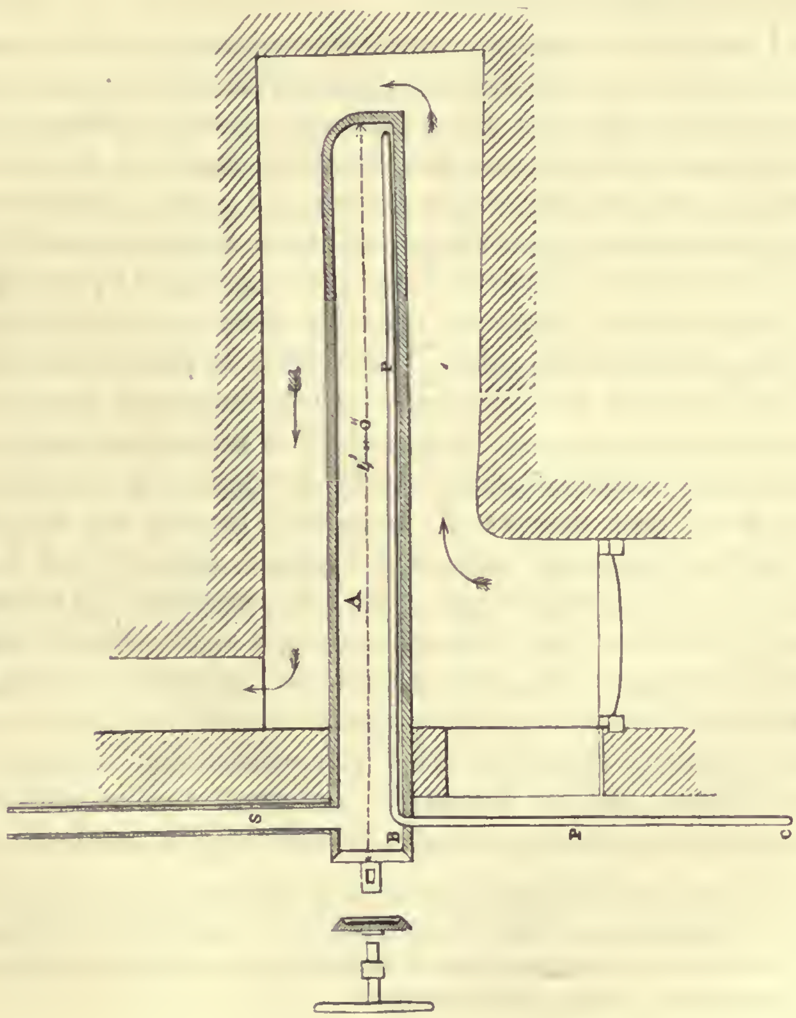
I have before observed that it is frequently difficult to detect the good from the bad kinds of coal, and in large operations it would not be prudent to rely solely on the judgement: I have known men of the greatest practice completely deceived. A specimen with a perfect fracture and lustre may produce inferior gas, and that which upon inspection would be rejected may yield gas in abundance and of excellent quality. It is therefore essential to prove the coal*, and this may be done in the manner shown in the annexed woodcuts, Figs. 6 and 7.

A is the cast-iron retort, 4 feet long, 12 inches wide, and 4 inches high, set in a furnace exposed directly to the flame, the flue passing beneath and over it, without guard of any kind, and secured into the side-walls by the snugs, *b b*. P P is a wrought-iron welded tube, about $\frac{3}{8}$ inside diameter, inserted into the retort at B, and running the entire length; from B outwards it is bent in the form of a gauge, and must not be less than three feet from B to C; at the socket D, one foot from the bottom bend, a glass tube about 24 inches long is firmly fixed by a little plaster of Paris: the whole tube from the retort to the commencement of the glass should be thickly wrapped with flannel or woollen listing (the thicker the better), to ensure an unvarying temperature. Pour mercury into the glass tube until it is just visible at D: heat the retort to a bright red by daylight for a few hours, to decompose

* Of course the coal supplied from a known main need not be subjected to this test; but that procured from new districts I should certainly advise to be tried by the method described.

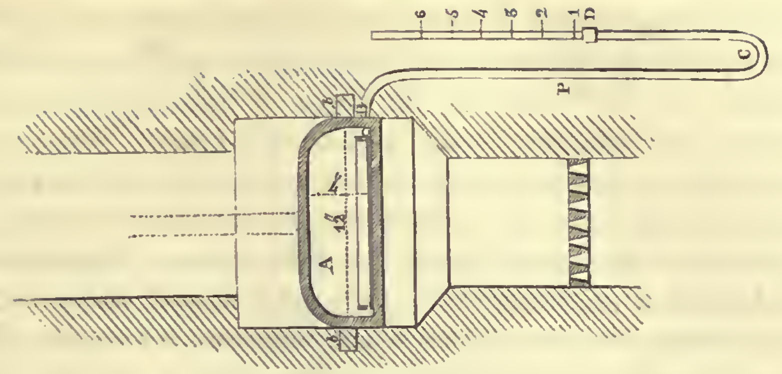
EXPERIMENTAL RETORT.

Fig. 6.



Longitudinal Section.

Fig. 7.



Transverse Section.

all vapour in the gauge; mark the glass gauge as the mercury rises (as at 1, 2, 3, etc.), fixing a point (say for instance at 6) for the heat at which the distillation is to be carried on (say 27° Wedgewood, the degree of heat at which copper melts), and the apparatus is then ready for the reception of the coal*. The coal must be prepared as follows:—sift a quantity through a sieve with meshes about three-eighths of an inch apart, and then through another much finer, so that the smallest pieces of coal used will be about the size of coffee-berries. Weigh correctly 3¼ pounds, and spread it over a surface of 360 square inches; that is, on a tray of sheet-iron, 10 inches wide and 36 inches long, turned up at the sides. Have the lid of the retort ready luted, and when the gauge marks 6, introduce the coal on the tray and immediately secure the lid.

Before I describe the remaining portion of the apparatus, it will be necessary to make a few remarks upon the necessity of having the barometric gauge attached to the retort. In the first place, then, if the heat at which the distillation is carried on were not uniform in all the experiments with the same coal, the results would vary from 50 to 60 per cent. both in quantity and quality. If the retort is too cold, nitrogen and hydrogen are liberated and unite, forming ammonia, vapour of bitumen (which afterwards condenses, forming tar, ammoniacal liquor, and essential oil), and carbonic oxide. If the retort is too hot, all the dense hydro-carburets are resolved into charcoal and hydrogen; the product is greater, but the specific gravity little more than that of hydrogen, and the illuminating power of the gas decreased in the same ratio. At the heat of 27° of Wedgewood, or that of melting copper, which has been found the best for Newcastle coal, the bitumen is decomposed, at the same time that the hydrogen is liberated and unites with its carbon, forming olefiant and carburetted hydrogen gases, often of the specific gravity 0·470. The quantity of gas of the above specific gravity produced from 3¼ pounds of the Pelaw main Newcastle coal ought to be about 19 cubic feet in one quarter of an hour. The operation must not be carried on too long, for the process in the end would be productive almost exclusively of carbonic oxide and hydrogen. Nearly all varieties of coal require different degrees of heat for their efficient distillation, and the duration of the charge requires equal attention. Three experiments are therefore advisable for each variety of coal tried; the heats

* It is always well to have a certain fixed degree of heat, such as the melting-point of tin, marked as 1 on the glass gauge—lead, marked 2, and so on,—both because errors are then less likely to occur, and memoranda, when referred to, more readily understood. The mercury will always indicate the same for the same temperature.

and the length of time the coal is subjected to that heat being varied in each until the best result is obtained: the *colour* of the hot retort is afterwards the guide in practical operations.

The gas, as it is produced in the experimental retort, escapes by the stand-pipe S (which ought to be at least seven feet long, to allow some portion of the bituminous vapour to fall back and be converted into gas), and passes through one or two other vertical pipes to the gas-holder, in order that it may be thoroughly condensed: at the bottom bends of these pipes a siphon must be attached, furnished with a stopcock to draw off the tar and other condensed vapours that will be deposited. The cup, it will be obvious, is absolutely necessary, otherwise the condensed vapours would seal the pipes and stop the flow of the gas.

The tank of the gas-holder should contain as little water as possible, for the reason I shall state hereafter. It is formed of two concentric cylinders, two inches apart, filled with water, between which the rising part works: the whole is fixed in a frame on which pulleys rest to support the specific gravity chain and balance-weights. The chain is best made of stout tape, with pieces of sheet-lead sewn on to it, equal to the difference between the weight of the gas-holder when *out* of the water, and when immersed *in it*.

The operation being concluded, it only remains to analyse the gas, which should be done as soon as it is produced, by the processes explained in a previous chapter.

The intensity of light is ascertained mechanically by an instrument called the Photometer, invented by Count Rumford; it is constructed on the principle that the power of a burning body to illuminate any defined space is directly as the intensity of the light, and inversely as the square of the distance. If two unequal lights shine on the same surface at equal obliquities, and an opake body be interposed between each of them and the illuminated surface, the two shadows must differ in intensity and blackness, for the shadow formed by intercepting the greater light will be illuminated by the lesser light only; and inversely, the other shadow will be illuminated by the greater light, that is, the stronger light will be attended with the deeper shadow: but it is easy, by removing the stronger light to a greater distance, to render the shadow which it produces not deeper than that of the smaller, or of precisely the same intensity; this equalization being effected, the quantity of light emitted by each lamp or candle will be as the square of the distance of the burning body from the illuminated surface.

If, when the candle is placed at 1, the two shadows are equal, the lamp only

N

gives a light equal to one candle; if at 2, the lamp is equal to four candles; and if at 4, the lamp is equal to sixteen candles.

A simple rule-of-three statement will give the comparative quantities of light, the candle being at any distance. The burner remaining 5 feet from the interposed wire, supposing the candle to be $1\frac{5}{10}$ of a foot from its wire,

The square of $1 \cdot 5 = 2 \cdot 25$.

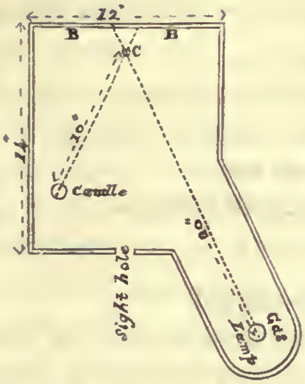
The square of $5 \cdot 0 = 25 \cdot 00$.

Then as 2·25, the square of the candle's distance, is to 1·,

so is 25·00, the square of the lamp's distance, to 11·11, the number of candles the gas-lamp is equal to.

The candle should be of the same size for all the experiments, and of spermaceti: the lamp should consume about $4\frac{1}{2}$ cubic feet of gas each hour. The great objection to the shadow photometer, as usually constructed, is, that the exposed flames communicate light to surrounding objects, and the photometer measures the whole quantity of this light, instead of only the radiated portion of it; besides the exposed flames destroy the power of the eye to form an accurate comparison of the shadows thrown upon the back of the box: to obviate this, the candle and the gas-flame should both be enclosed, and no light whatever suffered to escape. There is another inconvenience attendant upon the present mode of manipulation. The adjustment of the lamp to its proper consumption of gas per hour, and to its distance from the cylinder intercepting the light, occupies time, and requires very nice handling: indeed the results are much more liable to be influenced by the operator than those derived from a practical utensil should be. The following method of obtaining a true shadow-test, and the quantity of gas consumed by the lamp, is preferable to that described above:—Fix the candle, say ten inches from the shadow-rod C in Fig. 8, and by means of a spring maintain it at the same height, and fix the gas-lamp, consisting of five or six jets, in a row, at twice that distance from the same point; then by means of a cock adjust the gas-flame until its shadow is equal to that cast by the candle: the gas-lamp will be equal to four candles: the quantity of gas consumed being then measured by a meter will give its photometric value. When the lamp is placed at a much greater distance than twenty inches the *colours* of the shadows are different, and it is difficult to ascertain when they are of the same intensity. Between the meter and the gas-lamp should be placed a very delicate governor, weighing not more than $1\frac{1}{2}$ ounce, and balanced by a weight attached by a fine silken cord suspended over a wheel, bearing upon friction wheels. Combined jets of flame yield a greater quantity of light

Fig. 8.



in proportion to their consumption than single jets; the testing lamp should therefore be large enough to obviate any danger of a false result arising from this cause. Some descriptions of gas require particular burners, which should consequently be used in the experiments. Fig. 8 represents a tin box painted black inside except at the back B B, which must be japanned white, as must be also the cylinder C.

It will be found that the illuminating power of the gas is almost directly as the specific gravity; the heavier the gas, the greater the light given. If gas of sp. gr. 0·300 gives the light of six candles, that of sp. gr. 0·500 will give the light of ten candles, or nearly so. Mr. Clegg ascertained the fact in 1817 from many experiments.

The quantity and description of coke yielded by a specimen of coal cannot be ascertained by the apparatus just described, and, if desired, it must be done in one of the working retorts, weighing the coal when it is charged, and re-weighing the coke when drawn; the quantity ought to be about from 28 lbs. to 34 lbs. per 56 lbs. of coal. It should be granular and compact, the particles shining with somewhat of a silvery lustre, and when exposed to a white heat it should leave no white or brown ashes. The following is an average result of five experiments made after the plan just described:—

August, 1821.—Heat of experimental retort, 27° Wedgewood.—3¼ lbs. of Berwick and Craister's Wallsend coal yielded—in 10 minutes 16½ cubic feet—in 20 minutes 20 cubic feet. Sp. gr. of first portion 0·471; of second portion 0·432: burnt from an Argand lamp consuming 6·2 cubic feet of gas per hour. The first

portion gave a light equal to that of twelve candles called short sixes; the second portion required nearly seven cubic feet to produce the same effect.

The analysis of 100 cubic inches of the first portion was as follows:—

Olefiant gas	8
Carburetted hydrogen . .	72
Carbonic oxide and hydrogen .	13
Carbonic acid	4
Sulphuretted hydrogen . .	3
	100

The second portion was not analysed.

In Mr. Nicholson's Philosophical Journal for June 1805, and in the Transactions of the Royal Society for 1808, will be found a communication from Dr. Henry, on the illuminating power of combustible gases obtained from coal, admitting of more exact appreciation than the optical method by the comparison of shadows. The method to which he gave the preference was the determination of the quantities of oxygen gas consumed, and of carbonic acid formed by the combustion of equal measures of the different inflammable gases,—that gas having the greatest illuminating power which in a given volume condensed the largest quantity of oxygen gas. He found that 100 measures of pure hydrogen required only 50 of oxygen for its saturation, whereas 100 measures of olefiant gas required 284 of oxygen for its complete combustion: the former produced no carbonic acid, the latter produced 179 measures. The following Tables will show the results he obtained:—

One hundred measures of gas from coal of average quality obtained at Clifton, near Manchester,				
Consisting of			Consume of Oxygen	Give of carbon. acid
Olefiant.	Other inflammable gases.	Nitrogen.		
10	90	0	164	91
9	91	0	168	93
6	94	0	132	70
5	80	15	120	64
2	89	9	112	60
0	85	15	90	43

One hundred measures of gas from Cannel coal,				
Consisting of			Consume of Oxygen	Give of carbon. acid
Olefiant.	Other inflammable gases.	Nitrogen.		
18	77¼	4¾	210	112
16	64	20*	180	94
15	80	5	200	108
13	72	15	176	94

* The inferior illuminating power of this gas is owing to the presence of so large a portion of nitrogen. It certainly is a more than average proportion for any gas.

It appears from these experiments that gas from cannel coal has, with equal volumes, an illuminating power about one-third greater than that from coal of medium quality. The quantity also from the former substance exceeded by about one-seventh that obtained from common coal.

In comparing the value of gases produced from different kinds of coal, or from the same kind of coal differently treated, it is not enough to determine the *quantity* of aeriform products; and no satisfactory conclusion can be drawn respecting the relative fitness of any variety of coal for affording gas, or the advantages of different modes of distillation, unless the *degrees of combustibility* of the gases compared be determined by finding experimentally the proportion of oxygen gas required for their saturation. But, as I have before stated, the specific gravities of the various gases form as correct a method of judging of their illuminating qualities as any other, the lighter gas being the poorest. A gas having the specific gravity of 0·400 I have found, by a great number of experiments on a large practical scale, to be an average standard for comparison. The gas produced from cannel coal will average much higher. I have not had an opportunity of making such experiments on this gas as I should wish, to be relied on, as those of practical utility require to be made on a working scale. I think, however, the sp. gr. 0·539 is about the standard. Mr. Clegg obtained once, and once only, gas from a specimen of Wigan cannel, having the specific gravity of 0·640. I have not added this in with the rest for the average, because it is not a general result.

Table of the Specific Gravity of Coal-Gas, obtained from different Experiments.

Dr. Henry obtained	·600	Mr. Cooper	·415
———	·431	———	·410
———	·340	Mr. Anderson	·650
Dr. Dalton	·534	Mr. Clegg	·640
———	·443	———	·584
———	·410	———	·470
———	·390	———	·410
Dr. Faraday	·430	———	·406
Mr. Lowe	·425	———	·400
———	·408	———	.390
Professor Leslie	·600	———	·380
———	·410	———	·380
Mr. Phillips	·406	———	·370

Corrections for Moisture in Gas.

Gases expand by heat in the proportion of about $\frac{1}{480}$th of their bulk for every degree of Fahrenheit's thermometer between 32° and 212°; at a temperature of about 1035° Fahr. one volume of gas becomes nearly 2·5*. Dr. Dalton and Gay Lussac have proved beyond doubt that all gases expand equally by the same increase of caloric when placed under the same circumstances: it is therefore easy to ascertain the volume any given quantity of gas should occupy under any given temperature. As it may be useful sometimes in experiments to know the volume a portion of gas would occupy at a temperature differing from that in which the experiment is made, the following formulæ will be found correct.

Let V′ be the volume of gas at any temperature above 32°, T the number of degrees above that point, and V its volume at 32°: then $V' = \left(1 + \frac{T}{480}\right)$: hence $\frac{V'}{V} = 1 + \frac{T}{480}$; $V'\,480 = V\,(480 + T)$; and $V' = V\,\frac{(480 + T)}{480}$; or if V is unknown, it may be calculated by the formula $V = \frac{V'\,480}{480 + T}$.

It frequently happens, in using Fahrenheit's thermometer, that when V′ for the above formula is known, it is not V itself which is wanted, but the volume of gas at some other temperature, as at 60° Fahr.; this value may be obtained without first calculating what V is. Let V′, for instance, be any known quantity of gas at a certain temperature, and let V″ be the quantity sought at some other temperature, the degrees of which above 32° may be expressed by T′. Now $V'' = \frac{(480 + T')}{480} \times V$; but as V is unknown, let its value be substituted according to the above formula. Thus $V'' = \left(\frac{480 + T'}{480}\right) \times \left(\frac{V'\,480}{480 + T}\right)$, which gives $V'' = \frac{480^2\,V' + 480\,T'\,V'}{480^2 + 480\,T} = \frac{V'\,480\,(480 + T')}{480\,(480 + T)} = \frac{V'\,(480 + T')}{480 + T}$. Suppose, for example, a portion of gas occupies 100 divisions of a graduated tube at 48° Fahr., how many will it fill at 60° Fahr.? Here $V' = 100$; $T = 48 - 32$ or 16; $T' = 60 - 32$ or 28, the number sought, or the $V'' = \frac{100 \times 508}{496} = 102{\cdot}42$.

This formula was given by the late Dr. Turner, in his Lectures at the University of London, 1830. See also his work on Chemistry.

In estimating the volume of a gas, it is necessary that it be dry, as vapour in-

* Davy, Phil. Trans. 1817, p. 54.

creases it, and the augmentation will depend upon the temperature. Dr. Dalton has given a formula for the correction of moisture in gases.

Let a = weight of 100 cubic inches of dry common air, at the pressure of 30 inches, and temperature 60° Fahr.; p = any variable pressure of atmospheric air, and f = pressure or tension of vapour in any moist gas; then the following formulæ will be found useful in calculating the volumes, weights, and specific gravities of dry and moist gases, putting M for the volume of moist gas, D for that of dry gas, and V for that of vapour, all of the same pressure and temperature.

1. $M = D + V.$ 2. $\frac{p-f}{p} M = D.$

3. $\frac{f}{p} M = V.$ 4. $M = \frac{pD}{p-f} = \frac{pV}{f}.$

If we wish to infer the specific gravity of any dry gas from the observed specific gravity or weight of the same mixed with vapour, it will be convenient to expound p by that particular value which corresponds with a, namely, thirty inches of mercury; and let s = the specific gravity of the dry gas, and w = the observed weight of 100 cubic inches of the moist gas; then we shall have the following:—

5. $\frac{30-f}{30}. sa + \frac{f}{p} \times \cdot 620\, a = w.$ 6. $s = \frac{30}{30-f\,a} \left(w - \frac{f}{p} \times \cdot 620\, a\right).$

Examples.

1. 98 volumes of dry air + 2 volumes vapour = 100 volumes of moist air.

2. Given $p = 30, f = \cdot 5$ and $M = 100$; then $\frac{p-f}{p}. M = D$, the dry air $= 98\frac{1}{3}$.

3. And $\frac{f}{p} M = V$ the vapour $= 1\frac{2}{3}$.

4. Given $D = 100, p = 30, f = \cdot 4$; then $\frac{30 \times 100}{29{\cdot}6} = 101{\cdot}35$ the moist air.

Given $V = 2, p = 30, f = \cdot 3$; then $\frac{30 \times 2}{\cdot 3} = 200$, the moist air.

5. Let $f = \cdot 5$, $s = 1{\cdot}111$, $a = 30{\cdot}5$, $p = 29{\cdot}5$; then $\frac{30 - \cdot 5}{30}\ 1{\cdot}111 \times 30{\cdot}5$ $+ \frac{\cdot 5}{29{\cdot}5} \times \cdot 62 \times 30{\cdot}5 = 33{\cdot}64 = w$, which gives the specific gravity $1{\cdot}103$.

6. Let f, a, and p as above, and $w = 2{\cdot}5$ corresponding to specific gravity $0{\cdot}8197$; then $s = \frac{30}{29{\cdot}5 \times 30{\cdot}5} \left(2{\cdot}5 - \frac{\cdot 5}{29{\cdot}5} \times \cdot 62 \times 30{\cdot}5\right) = \cdot 07266.$

The above formulæ will apply equally well if V be a permanent gas, or any other vapour beside that of water, the specific gravity of the gas or vapour being substituted instead of ·620,—that of steam.

The following is extracted from Professor Faraday's 'Chemical Manipulation,' p. 381 :—

"Gas, when standing over water, becomes saturated with aqueous vapour, the quantity being proportional to the temperature. In these cases a part of the volume observed, and also a part of the weight, is due to the vapour, which therefore must be ascertained before the true weight of the gas under examination can be determined. The following Table exhibits the proportion by volume of aqueous vapour existing in any gas standing over or in contact with water, at the corresponding temperatures and at mean barometric pressure of 30 inches :—

40°—·00933	51°—·01380	61°—·01923	71°—·02653
41 —·00973	52 —·01426	62 —·01980	72 —·02740
42 —·01013	53 —·01480	63 —·02050	73 —·02830
43 —·01053	54 —·01533	64 —·02120	74 —·02923
44 —·01093	55 —·01586	65 —·02190	75 —·03020
45 —·01133	56 —·01640	66 —·02260	76 —·03120
46 —·01173	57 —·01693	67 —·02330	77 —·03220
47 —·01213	58 —·01753	68 —·02406	78 —·03323
48 —·01253	59 —·01810	69 —·02483	79 —·03423
49 —·01293	60 —·01866	70 —·02566	80 —·03533
50 —·01333			

By reference to this Table, which is founded upon the experiments of Dr. Dalton, and includes any temperature at which gases are likely to be weighed, the proportions in bulk of vapour present, and consequently of the dry gas, may easily be ascertained. For this purpose, the observed temperature of the gas should be looked for, and opposite to it will be found the proportion in bulk of aqueous vapour, at a pressure of thirty inches. The volume to which this amounts should be ascertained, and corrected to mean temperature. Then the *whole* volume is to be corrected to mean temperature and pressure, and the corrected volume of vapour subtracted from it: this will leave the corrected volume of dry gas. It has been ascertained, in a manner approaching to perfect accuracy, that a cubic inch of permanent aqueous vapour, corrected to the temperature of 60°, and a mean pressure of 30 inches, weighs 0·1929 grains; the weight therefore of the known volume of aqueous vapour is now easily ascertained, and this being subtracted from the weight of the moist gas, will give the weight of the dry gas, the volume of which is also known.

As an illustration, suppose a gas standing over water had been thus weighed, and that 220 cubic inches (at the temperature of 50° Fahr., and barometer pressure of 29·4 inches) had entered into the globe, and caused an increase in weight of 101·69 grains. By reference to the Table, it will be found that at the tem-

perature of 50° the proportion of aqueous vapour in gas standing over water is ·01333, which, in the 220 cubic inches, will amount to 2·933 cubic inches, which, corrected to the temperature of 60°, becomes 2·942 cubic inches. The whole volume corrected to mean temperature and pressure will be found to equal 219·929 cubic inches, from which, if the 2·942 cubic inches of aqueous vapour be subtracted, there will remain 216·987 cubic inches as the volume of *dry* gas at mean temperature and pressure; 2·940 cubic inches of aqueous vapour weigh ·5675 grains, for $2·942 \times 0·1929 = 0·5675$; this subtracted from 101·69, the whole weight, leaves 101·1225 grains, which is the weight of the 216·987 cubic inches of dry gas; and by the simple rule of proportion, therefore, it will be found that 100 cubic inches of such gas, when dried, and at a mean temperature and pressure, will weigh 46·603 grains.

Some experimenters prefer drying the gas before it is weighed, and thus in fact weigh a known volume, not of a mixture, but of a pure gas. Now gases are dried in various ways; one method is to pass them through a glass tube containing substances having a powerful attraction for water: it is a simple and a useful process, and therefore proper to be described here, though not conveniently applicable to the mode of weighing a gas as above directed, because of the greater difficulty of measuring the quantity of gas which enters. The tube may be about half an inch in diameter, and two feet long, and should have a piece of wire pressed into a loose ball thrust into one end of it, to prevent fragments falling through. Chloride of lime should be heated and fused in an earthenware crucible —a temperature below that of visible redness being quite sufficient for the purpose—then poured upon a clean metallic or stone surface, and, as soon as it has solidified, broken up and put into stopped bottles. This chloride, being divided into a mixture of large and small fragments, is to be introduced rapidly into the tube, until the latter is nearly full; the apparatus is then ready for use. The tube may be connected with the jar-gasometer, or other vessel containing or evolving the gas, by caoutchouc connectors, or in any other convenient way; and so much gas should be passed through it, as effectually to expel all the common air before the globe or vessel to be filled with the dry gas be attached. That being done, the gas should be allowed to pass slowly, 100 cubic inches having about ten minutes allowed for their passage through such a tube as that described; though if the period be lengthened, no injury is occasioned. If the tube be shorter, or of smaller diameter, more time should be proportionally allowed. Dr. Thomson has published a very useful method of weighing gases in the Annals of Philosophy, vol. xv. p. 352.

ADVANTAGES OF GAS.

All substances, whether animal, vegetable, or mineral, consisting of carbon, hydrogen, and oxygen, when exposed to a red heat, as we have already seen, produce various inflammable elastic fluids, capable of furnishing artificial light. We perceive the evolution of this elastic fluid during the combustion of coal in a common fire. The coal, when heated to a certain degree, swells and kindles, and frequently emits remarkably bright streams of flame, and after a certain period these appearances cease, and the coal glows with a red light.

The flame produced from coal, oil, wax, tallow, or other bodies which are composed of carbon and hydrogen, proceeds from the production of carburetted hydrogen gas, evolved from the combustible body when in an ignited state.

If coal, instead of being burnt in the way now stated, is submitted to a temperature of ignition in close vessels, all its immediate constituent parts may be collected. The bituminous part is distilled over, in the form of coal-tar, etc., and a large quantity of an aqueous fluid is disengaged at the same time, mixed with a portion of essential oil and various ammoniacal salts. A large quantity of carburetted hydrogen, carbonic oxide, carbonic acid, and sulphuretted hydrogen, also make their appearance, together with small quantities of cyanogen, nitrogen, and free hydrogen, and the fixed base of the coal alone remains behind in the distillatory apparatus, in the form of a carbonaceous substance called *coke*. An analysis of the coal is thus effected by the process of destructive distillation: the products which the coal furnishes may be separately collected in different vessels.

The carburetted hydrogen, or coal-gas, when freed from the obnoxious foreign gases, may be propelled in streams out of small apertures, which, when lighted, form jets of flame, which are called *gas-lights*.

In order to apply this mode of procuring light on a large scale, as now practised with such brilliant success in this country, as well as in many parts of America and continental Europe, the coal is put into vessels called retorts, and furnished with pipes connected with reservoirs, to receive the distillatory products. The retorts are fixed into a furnace, and heated to redness: the heat developes the gaseous and liquid products of the coal: the latter are deposited in receivers

or tanks, and the former conducted through lime-water, or thin strata of the hydrate of lime, and purified. The sulphuretted hydrogen and carbonic acid, which are mixed with these, become absorbed by the lime and moisture, and the pure carburetted hydrogen is stored up in a vessel called a gasometer, and is then ready for use. From the reservoir in which the gas has been collected proceed pipes, which branch out into small ramifications, until they terminate at the place where the lights are wanted; and the extremities of the branch pipes are furnished with stop-cocks, to regulate the flow of the gas into the burners or lamps.

The production of gas-lights is therefore analogous to that of flame produced from tallow, wax, or oil. All these substances possess, in common with coal, the elements of certain peculiar matters, which are capable of being converted into inflammable elastic fluids by the application of heat.

The capillary tubes formed by the wick of a candle or lamp serve the office of the retorts placed in the heated furnace in the gas-light process, and in which the inflammable gaseous fluid is developed. The wax, tallow, or oil, is drawn up into these ignited tubes, and is decomposed into carburetted hydrogen gas, and from the combustion of this substance the illumination proceeds. In the lamp, as well as in the candle, the oil or tallow must therefore be decomposed before they can produce a light; but for this purpose the decomposition of a minute quantity of the materials successively is sufficient to give a good light: thus originates the flame of a candle or lamp.

Nothing more therefore is required in the gas-light process which coal affords, when submitted to a temperature of ignition in a close vessel, than to collect these products in separate reservoirs, and to convey one of the products, the inflammable gas, by means of pipes and branching tubes, to any required distance, in order to exhibit it there at the orifice of the conducting tube, so that it may be used as a candle or lamp.

The whole difference between the greater process of the gas-light operation and the miniature operation of a candle or lamp, consists in having the distillatory apparatus at the gas-light manufactory, at a distance, instead of being in the wick of the candle or lamp,—in having the crude inflammable matter decomposed, previous to the elastic fluid being wanted, and stored up for use, instead of being prepared and consumed as fast as it proceeds from the decomposed oil, wax, or tallow; and lastly, in transmitting the gas to any required distance, and igniting it at the burner or lamp of the conducting tube, instead of burning it at the apex of the wick. The principle of the gas-light manufacture is therefore precisely

similar to the general mode in which all light is produced: it is simply conducting on a large and general scale the natural operations of ignition.

Greatly as the number of towns lighted with coal-gas have increased within the last few years, when the brilliancy, economy, and convenience of this mode of illumination is considered, it is surprising that there remains a single town, deserving the name, without its gas-works. A small town cannot be supplied with gas at so cheap a rate as a large one, because the cost of the apparatus, the labour, and wear and tear will be much greater in proportion; still I may almost say, without exception, a town of 200 consumers may be lighted with gas at a cost less than that which the inhabitants pay for oil and candles: a few figures will show this. Let the cheapest oil-lamp be taken as a datum, viz. the solar-lamp, burning fish-oil: one of these, kept perfectly in order, will yield light equal to about five mould candles of six to the pound; and presuming the light to be required from sunset to ten o'clock every night during the year, or for 1400 hours, it would burn about $15\frac{1}{2}$ gallons of oil, which, at 4*s.* per gallon = £3 2*s.* per year; an Argand gas-burner, consuming 3·25 cubic feet per hour, would also give a light equal to five mould candles, and would consume during the 1400 hours, 4550 cubic feet, and, allowing interest for the fittings and meter, gas at 10*s.* per 1000 would be as cheap; but how much more safe, cleanly, and convenient need not at the present day be pointed out: 200 burners at this price would yield £455 per year gross rental, and presuming the cost of production and distribution to amount to 5*s.* per 1000 (which is extreme) the interest would be more than 10 per cent. on the capital expended for a very straggling town. But this is not a fair method of estimating the cost of gas: a sixteen-hole Argand, burning five feet per hour of gas of same quality as the last, will give a light of thirteen candles, therefore, where more than one oil-lamp was required, as in a shop-window, the saving by gas would be very great indeed, even at this high price.

The relative values of gas-light, and that derived from candles, etc., is given in a very clear and concise manner by Mr. Rutter, in a small book entitled 'Advantages of Gas in Private Houses,' published by Messrs. Parker and Son, West Strand, and I take the liberty of quoting therefrom.

"The only correct method of estimating the relative cost of gas-light, and of that obtained from tallow, wax, and oil, is by instituting the comparisons with equal quantities of light; each of the light-giving materials being used under the most favourable circumstances, and strictly in accordance with the plans pursued in actual practice. When gas is first introduced, it rarely happens that persons are satisfied with the same quantity of

light as they had previously possessed. So long however as this extra supply is kept within moderate limits, it will cause no material difference in the results of the following calculations, since, with ordinary care, there need be no waste in the use of gas, whilst the most skilful management will not prevent waste with candles and lamps. Adopting as standards of comparison the following prices, namely:—

Tallow candles (dips)	6*d*. per lb.
Tallow candles (moulds)	8*d*. per lb.
Composition candles	1*s*. per lb.
Wax candles	2*s*. 4*d*. per lb.
Solar and pale seal oil	4*s*. per gallon.
Sperm oil	8*s*. per gallon.

The relative cost of equal quantities of light from each material, as compared with gas, at the respective prices quoted, will be as shown by the table.

"*Comparative Cost of Light from Candles, Lamps, and Gas**.

	Quantities and Prices of Candles and Oil.			Quantities and Prices of Gas.				
				Cubic Feet.	7*s*. per 1000.		6*s*. per 1000.	
		s.	*d*.		*s*.	*d*.	*s*.	*d*.
Tallow candles (dips)†	1 lb.	0	6	21	0	$1\frac{3}{4}$	0	$1\frac{1}{2}$
Tallow candles (moulds)	1 lb.	0	8	21	0	$1\frac{3}{4}$	0	$1\frac{1}{2}$
Composition candles‡	1 lb.	1	0	25	0	$2\frac{1}{8}$	0	$1\frac{3}{4}$
Wax candles	1 lb.	2	4	25	0	$2\frac{1}{8}$	0	$1\frac{3}{4}$
Solar and pale seal oil§	1 gall.	4	0	175	1	$2\frac{3}{4}$	1	$0\frac{5}{8}$
Sperm oil	1 gall.	8	0	217	1	$6\frac{1}{4}$	1	$3\frac{5}{8}$

* The prices of candles and oil, although subject to occasional alterations, are tolerably uniform at the same periods, in all parts of the kingdom. It is not so, and never will be so, with respect to the prices of gas, which, to a great extent, are dependent upon local circumstances. This is not sufficiently understood, and yet it admits of an easy explanation. Coal being the staple material used in the manufacture of gas, the cost of which, taking the very lowest rates, varies in different localities from 4*s*. to 23*s*. per ton, it is evident that the prices of gas must thereby be affected. Nor is this the only cause of difference in prices: the cost of production, other conditions being equal, is greater in small establishments than in large ones. It would be as reasonable to expect that in small towns, or districts, gas could be supplied at as cheap a rate as in those of ten or twenty times the extent, as that a single shawl or piece of calico could be made by hand as cheaply as by machinery.

† Although dip candles cost less than moulds, they are liable to greater waste, and consequently cost, as respects light, as much as, or more than, the latter.

‡ The average duration of composition and wax candles is less by two hours than that of common candles, but they yield more light, very nearly in the proportion of six to five.

§ If common oil be not used in a lamp expressly adapted for its perfect combustion, the waste of oil and deficiency of light will be so great as to render the cost of light actually obtained equal to double the amount at which it is here stated.

"On referring to the table it will be seen that where the price of gas is, for example, 6*s*. per thousand, a quantity sufficient to produce light equal to that to be obtained from a pound of tallow candles at 8*d*. will cost only 1½*d*., that is, less than one-fourth the cost of candles; compared with wax candles, the cost of gas-light is only one-sixteenth; so also in comparison with the cheapest kinds of oil, the cost of gas-light is little more than one-fourth, and compared with sperm oil it is less than one-sixth."

Dr. Letheby's report to the City Commissioners of Sewers, dated 10th May, 1852, gives a comparative statement of the value of gas as an artificial light. He says:—

"When gas gives a light equal to that of twenty-three mould candles of six to the pound, each burning at the rate of 145 grains per hour; or that of eighteen common oil lamps, each burning the best sperm oil at the rate of 133 grains per hour; or to that of 2·5 Argand lamps, burning the same oil each at the rate of 450 grains per hour; or to that of thirteen sperm candles of six to the pound, each burning at the rate of 133 grains per hour; or to that of fifteen composite candles of six to the pound, each burning at the rate of 136 grains per hour. Now if we make an inquiry into the relative cost of these illuminating agents, we shall find that the facts thereof may be expressed as follows:—

Gas equal to	1
Sperm oil burnt in Argand	8
Mould tallow candles of six to the lb.	12
Sperm oil burnt in an open lamp	17
Sperm candles of six to the lb.	24
Composition candles of six to the lb.	29
Wax candles of six to the lb.	30

In other words, by estimating the cost of the gas at 4*s*. per 1000 cubic feet, the price of mould candles at 6*d*. per lb., the value of sperm oil at 8*s*. per gallon, and the price of wax, sperm, and composition candles at 2*s*. per lb., it may be said that a shilling's-worth of gas will go as far in the production of light as 8*s*. worth of sperm oil burnt in an Argand lamp, or 12*s*. worth of ordinary mould candles, or 17*s*. worth of sperm oil burnt in an open lamp, or 24*s*. worth of sperm candles, or 29*s*. worth of composition candles, or 30*s*. worth of wax candles."

Perhaps the greatest proof of the advantages of gas-light, and the most decided advance that has been made since its introduction towards its universal adoption by all classes of consumers, was that effected by the "Great Central Gas-Consumers' Company," who, confident in the integrity of its purpose and in the correctness of its views, combated single-handed against the all but overwhelming influences brought against it by the existing Companies. The struggle for suc-

cess was comparable only to that of the Chartered in 1815, but the elements of opposition were different; against the latter, ignorance of the value of gas and distrust as to its practicable distribution were arrayed; against the first, the closed ranks of monopolists rose up, who, with capital at command, followed the new Company, "*the invaders*," step by step, and strove with all their might to break it down*. The first Company had a negative, the last a positive opposition to withstand.

In the "Central Consumers' Company" the shareholders and the consumers have a mutual interest; their maximum dividend is fixed by Act of Parliament, and all profit beyond this must go towards supplying gas at a cheaper rate to its users. The maximum charge at the commencement was 4*s.* per 1000 cubic feet; and the Company are prepared when their annual trade reaches 420 millions to sell the gas at 3*s.* 6*d.* per thousand, and at 3*s.* when the quantity consumed is 720 millions annually.

The success of this Company has consolidated by law and practice a sound system, applicable to gas and all other objects in which the public service and private enterprise are blended,—a system of regulated management, equally removed from centralization on one hand, and from recklessness of speculation and selfishness of monopoly on the other.

Ten per cent. may appear a high dividend for the shareholders to receive before reducing the price of gas to the consumers, but no Company would be wise in fixing a lower rate. The profit of investments in the manufacture of gas and other productions of mechanical and chemical skill and science must not be measured by the same standard with capital laid out in commercial establishments, from which it can be easily withdrawn, or in permanent reproductive employments not liable to be supplanted by new inventions, which in matters dependent on skill and science are perpetually starting up to baffle the calculations of the most prudent. We may not, and do not, expect that, at least in our day, electric light, or any other substitute for the illuminating agency of gas, will be brought to bear; but after the employment of electricity as the medium of intercommunication between distant kingdoms, who shall presume to define the limits of human invention in the service of mankind? No prudent person can treat dividends on gas-shares as the usufruct of capital without setting apart some portion of its amount to provide

* The Central Consumers' Company went three successive sessions to Parliament before they obtained their Act of Incorporation, and the money expended in the conflict was not less than £50,000.

against the contingencies to which all property of that description is sooner or later exposed*.

The outlay in the first instance, the labour required for the operation, the quantity of coals and material expended, together with the returns, are now so fully understood, and can be calculated to such a nicety, that money sunk in the erection of gas-works returns its interest with the same certainty as that deposited in the funds. It is not a speculation, but a matter of the same kind as the commencement of a factory for the production of any other article of commerce.

While thus speaking of the certainty of success attending the manufacture of coal-gas, it must be understood that the apparatus erected for that purpose be designed and executed with skill. Individuals, from observing the excellent returns given for the capital expended on other establishments, have been induced to erect works of their own, expecting naturally an equal remuneration. From employing ignorant people, their arrangements have in many cases signally failed, and I doubt not that these circumstances alone have tended in a great measure to retard the general diffusion of gas-illumination throughout the entire kingdom.

If the number of lamps required is known, the materials necessary for the production of the gas to supply those lamps are known also. The profit and loss of such establishments in actual operation may as surely be relied upon as that given upon paper.

Upon a well-regulated system the cost of producing every 1000 cubic feet of gas with the same coal will not vary one penny the whole year round; the quantity of gas made will be adequate to the demand, and no more. The wear and tear of the machinery will be exactly that which was anticipated, and therefore the annual outlay will be known; the sale of the products of the establishment may be depended upon with equal certainty, and the income known: the profit arising from the difference is thus ascertained. I will give as an example the results of a small gas establishment erected in the country.

	£.	s.	d.
Apparatus for the supply of 70 public and 75 private lamps cost	500	0	0
Retort-house and chimney	130	0	0
400 yards of 4-inch pipe	101	13	4
740 ditto 3-inch ditto	129	0	0
266 ditto ditto	39	13	0
	£900	6	4

* Address from the directors of the Central Gas-Consumers' Company, Sept. 28, 1852.

OUTLAY IN 1838.

	£.	s.	d.
Coal carbonized	204	17	11
Ditto as fuel	54	15	0
240 bushels of lime	6	0	0
One man by day and one by night	62	8	0
Lamplighter	31	0	0
Repairs in the streets	15	0	0
Repairs in the works, including wear and tear of retorts, meter, and clock	60	0	0
Rent of ground	20	0	0
Taxes	20	0	0
Office expenses	10	0	0
	£484	0	11

INCOME IN 1838.

	£.	s.	d.		£.	s.	d.
72 Private lamps at	3	0	0	=	216	0	0
64 Public ditto at	4	0	0	=	256	0	0
200 Gallons of tar at	0	0	1	=	0	16	8
Coke, 247 chaldrons, at	0	16	0	=	197	12	0
					£670	8	8

Therefore we have—

	£.	s.	d.
Income	670	8	8
Outlay	484	0	11
Leaving a profit of	£186	7	9

OUTLAY IN 1839.

	£.	s.	d.
Coal carbonized	204	19	2
Ditto as fuel	54	14	0
240 bushels of lime	6	0	0
One man by day and one by night	62	8	0
Lamplighter	31	0	0
Repairs in the streets	16	3	0
Repairs in the works, including wear and tear of retorts, meter, and clock	58	16	0
Rent of ground	20	0	0
Taxes	20	0	0
Office expenses	10	0	0
	£484	0	2

INCOME IN 1839.

	£.	s.	d.		£.	s.	d.
75 Private lamps at	3	0	0	=	225	0	0
64 Public ditto at	4	0	0	=	256	0	0
Coke, 243 chaldrons, at	0	16	0	=	194	8	0
					£675	8	0

Income	675	8	0
Outlay	484	0	2
Leaving the profit . . .	£191	7	10

The equal results of these two years is not peculiar to this establishment; there are many of much greater extent that can compare with it. The following is the balance-sheet of a gas establishment in Scotland, extracted from the 'Journal of Gas-lighting,' September, 1852:—

Balance Sheet for the year ending May 15, 1852.

	£.	s.	d.	£.	s.	d.
Received for gas sold, 1,894,000 cubic feet, at 7*s.* 11*d.* .	749	14	2			
„ meters' rent, at 2*s.* each	22	0	2			
„ meters, coke, tar, and pipes sold . . .	17	6	2			
				789	0	6
Paid for Parrot coal, 203 tons	163	16	9			
„ Furnace coal, 87 tons	37	6	9			
„ lime	5	4	0			
„ retorts, bricks, and clay	11	15	0			
„ meters	35	3	9			
„ miscellaneous accounts	39	15	4			
„ public rates	16	18	4			
„ salaries	78	0	0			
„ wages on works and on streets	70	2	0			
				458	1	11
Nett gain				£330	18	7

Gas sold per ton of coal carbonized = 9365 cubic feet.

It is only those works, in the erection of which incompetent people have been employed, that fail to answer the expectations of the capitalist. It is at all times unpleasant to find fault; but it cannot be denied that there are many who, from slight or no experience at all, fancy themselves capable of undertaking the super-

intendence of any gas establishment: the number of failures constantly point out their ignorance. It is no better than imposition for persons thus unqualified to undertake the arrangement of such machinery, upon the correct working of which must depend its success; and those who suffer themselves thus to be imposed upon will only find out their error when it is too late to rectify it.

The manufacture of gas is one of those processes which appear perfectly simple and straightforward at first sight, and this may in some measure account for the errors of such men as I have just noticed. It is true that the operations do appear exceedingly plain; but there are few that require more scientific judgement, system, and strict care. The retorts, for instance, must be set in such a manner as to be heated sufficiently with the smallest quantity of fuel, and without the liability of being made too hot: they must be carefully watched, lest the incrustation of carbon in the interior accumulate more than is absolutely unavoidable, and lest they burn out before the time calculated. These particulars can only be learned by *practice;* they will vary with every different quality of coal, and be affected by the size and shape of the distillatory vessel itself. It also requires much experience to determine the most economical arrangements for the condensers, purifiers, etc., and to regulate the quantity of gas to the demand. But, above all, the proper distribution of the street-mains requires the most skill, which, in the section treating upon this subject, I shall endeavour to point out.

The supplying of light to the street or parish lamps alone can never be undertaken with economy in any district, the most beneficial application being in those situations where a quantity of light is wanted in a small space. Where the light is required to be more diffused, the profit is less, owing to the greater extent of services and fittings.

There are some disadvantages attending the use of gas-lights in a close room; for unless the apartment be well ventilated, an unpleasant heat will be felt, often producing at the same time the effect of sickness and oppressive head-ache. The capacity of ventilators adapted to rooms in which coal-gas is burned should greatly exceed that actually capable of carrying off the heated vapours; they should be made of tubes, opening from the top of the room at the angles formed by the meeting of the ceiling and sides, and carried into the open air by pipes several feet high, thus causing sufficient draught to ensure perfect ventilation. One pipe may be taken from the cornice over the chimney-piece and conducted up the flue, and the end of the tube covered by a hood. An Arnott's ventilator may be used with advantage. An adequate supply of fresh air must of course be ensured from the

bottom of the room. Dwelling-houses may thus be illuminated with advantage and comfort. The most perfect form of gas-lamp for a close room is that which takes its supply of atmospheric air from the outside, and delivers the products of its combustion at once into the open air, the light being alone diffused within the room. On this subject, and others connected with lamps and burners, see the chapter upon them.

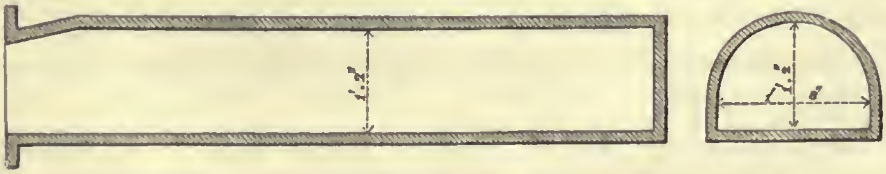
A gas-burner consuming five cubic feet per hour renders as much atmospheric air unfit for respiration as two adults. The comparative effect of heat evolved during the combustion of inflammable gases, and other substances capable of burning with flame, will be found in Dalton's 'System of Chemistry,' vol. i. p. 76.

RETORTS.

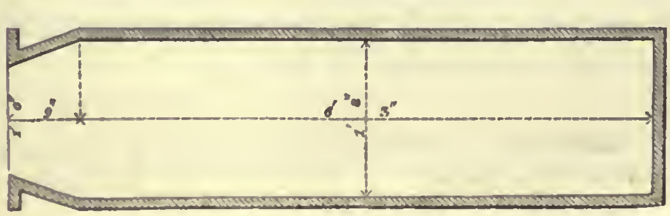
The proper mode of constructing retorts in which the coal is distilled, and the art of applying them, form objects of primary importance in every gas-light establishment. The quantity of gas which can be obtained in any given time from any given quantity of coal—the consumption of fuel requisite for the production of that quantity of gas—the degree of deterioration to which the distillatory vessel is subjected—the equality, in some measure, of the gas itself—all depend upon the manufacture being conducted with a due regard to physical principles, and, as the ultimate result of all these circumstances, the rate at which the gas-light can be furnished to the consumer.

The forms of the retorts used at the present time are various; I shall however confine my observations to those which are considered the best both for the production of gas, and for their durability. The annexed figures represent sections of a retort, commonly known by the name of a York D. The charge is 3 bushels, or $2\frac{1}{4}$ cwt., which may be drawn at the end of six hours. The dimensions cannot be increased with economy beyond those marked on the drawings. Retorts of smaller dimensions are more usually adopted; I have shown them, with the manner in which they are set, in an engraving.

Fig. 9.



Plan.



PLATES I. AND II.

MODE OF SETTING A BENCH OF FIVE D RETORTS.

These Plates represent a front elevation, two sections and plan of a "bench" of five common retorts, such as are in general use.

Plate I. Fig. 1 is a front elevation. Fig. 2. A transverse section, through *a b* in Fig. 3. Fig. 3. A longitudinal section, through *c d* in Fig. 2.

Plate II. Fig. 1 is a plan showing the furnace and side-openings below the fire-tiles, on which the lower retorts rest, and the bedding of the lower retorts. Fig. 2 is a plan over the three lower retorts, the two upper retorts being removed. Fig. 3 is a plan over the oven-arch, showing the flues, etc.

The same letters refer to corresponding parts in the several views.

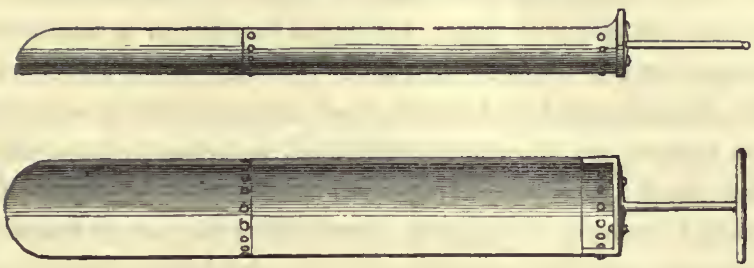
A. Retorts of the kind called D's. Some engineers prefer those of a cylindrical form, but D's allow of the coal being laid in thinner strata, consequently it is more evenly acted upon by the heat, an advantage under every circumstance. Set in the manner shown in the Plates, the bottoms of those retorts placed immediately over the furnace are well protected. The dimensions are—length 7 feet, diameter 1 foot 2 inches, thickness of metal $1\frac{1}{4}$ inch. Their weight is about 15 cwt.

The most economical charge is two bushels, or $1\frac{1}{2}$ cwt., of coal to each retort, drawn at the end of six hours. This charge will fill the retort to the depth of about five inches; if the coal be moderately small, the layer will be rather less in thickness. At a heat of 27° of Wedgewood's pyrometer, or that of melting copper, each charge ought to produce about 650 cubic feet of gas, of the specific gravity ·400*, from Newcastle coal, making the products of the entire bench equal to 3250 cubic feet in six hours.

To introduce the coal into the retorts, a "scoop" ought to be employed, in preference to the primitive mode, with a shovel. The scoop is a semi-cylinder made of thin plate-iron, six feet six inches long, and twelve inches in diameter, with a cross-handle at one end, represented in Fig. 10.

* The specific gravity varies between ·390 and ·420, according to the heat at which the retorts are worked, and the quality of the coal carbonized.

Fig. 10.



The charge for the retort is placed in this; one man takes the cross-handle, and two others at the opposite end lift it with its contents up to the retort; it is then pushed forward, quite to the bottom, turned round, and withdrawn immediately, and the coal left in the retort raked into an even stratum.

The lid, previously luted, is now quickly jointed on to the retort-mouth. It must be obvious that the loss of gas by this simple method is very trifling; indeed I much question whether any is lost, the whole operation not occupying more than forty seconds; whereas, when the shovel is used, the coal is thrown in so much by degrees, that more gas is lost, owing to the greater length of the operation, and the heat producing some effect on each separate shovel-full: in either case the loss is inconsiderable, but I am an advocate for saving in every possible way.

Previous to drawing the charge, loosen the lids of the retorts, and apply a light to the issuing gas, beginning at the upper retorts. This precaution is necessary to prevent explosion, or what the stokers call a "rap."

S is the mouth-piece, ten inches long, with a socket cast on the top to receive the stand-pipe. There ought to be a neck to this socket, as shown in the Plates; because the joint, when close upon the top, from its greater thickness, retains much heat, and decomposes the tar which will accumulate at this place, and eventually choke the pipe with hard carbon. The length of the neck may be from four to five inches. I have mentioned this, from having frequently observed the stand-pipe jointed immediately upon the mouth-piece.

The mouth-piece is three-quarters of an inch in thickness, secured to the retort by bolts, and a cement-joint made between their flanches. Iron cement is the most valuable for this purpose, and is used in all places where heat is present.

It may be compounded as follows. To one ounce of sal-ammoniac, add one ounce of flowers of sulphur, and thirty-two ounces of clean cast-iron borings: mix all well together, and keep the composition dry. When the cement is wanted for use, wet the mixture with water, and when brought to a convenient consistence, let it stand for a few hours; then apply it to the joints, and screw them together. The flanches ought to be kept about three-eighths of an inch apart, by wrought-iron wedges, and the cement well filled in between them with a square blunt-pointed chisel, called a caulking-chisel; the cement is stopped from being driven through by a hoop of thin iron placed inside the pipe or retort to be thus operated upon, which is afterwards removed. A considerable degree of action and reaction takes place among the ingredients, and between them and the iron surfaces, which causes the whole to unite as one mass; the surfaces of the flanches become joined by a species of pyrites, all the parts of which adhere strongly together. Mr. Watt found that the cement is improved by adding some fine sand from the grindstone trough.

A very economical joint for the retort mouth-piece is made of five parts of fine Stourbridge clay, and one part of the mixture just described.

For some purposes it is more convenient to join the parts not exposed to heat with putty, mixed to a proper consistence, and applied on each side of a piece of thick canvas, flannel, plaited hemp, or a piece of thick pasteboard steeped in linseed oil (previously shaped to fit the parts), and then interposed between the parts before they are screwed together: it makes a close and durable joint, and is generally used for those which have occasionally to be opened, and for those which must be separated repeatedly before a proper adjustment is obtained.

The face of the retort mouth-piece is bevelled inwards, and is chipped and filed, if necessary, to remove any lump that would prevent the lid from fitting close: a clean and true casting however seldom requires this to be done.

The lid is shown in Plate III. Figs. 6 and 7. It is jointed on to the face of the mouth-piece, with "luting" made of the spent lime from the dry purifiers, mixed with a little fire-clay, and tightened into its place by a strong square-threaded screw, and a cross-bar of wrought iron, the ends of the cross-bar being passed through projecting ears, against which it bears when the screw is turned.

B is the "stand-pipe," through which the gas, as it is generated, passes from the retort; it is three or four inches in diameter at the top, increasing to five inches at the bottom, to prevent the tar which adheres to the lower parts from

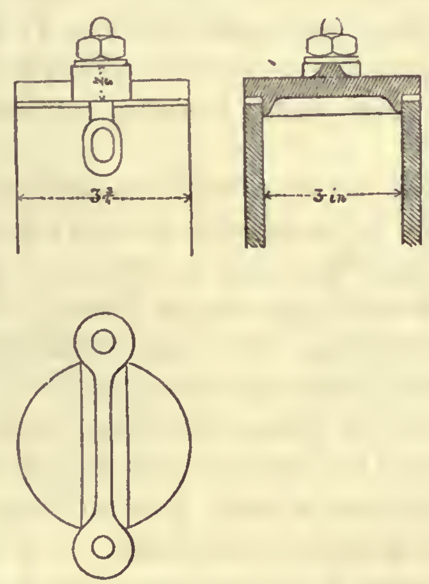
obstructing the flow of the gas. The lowest joint is made with a socket, instead of a flanch, to allow for some expansion without injury.

B′ is a "bridge-piece," connecting the stand and dip-pipes.

C is the "dip-pipe," passing through the upper metal of the hydraulic main, upon which it is jointed, and having its lower extremity, which is three inches in diameter, immersed four or five inches into the tar contained therein. The holes in the hydraulic main, through which the dip-pipes pass, are generally drilled and chipped out while the apparatus is in process of erection; because they are at unequal distances from one another, and to have them fixed "out of square" would be an eye-sore. The height of the dip-pipes from the surface of the tar, measured from the lower bend of the bridge-piece, ought to be sufficient to contain the perpendicular head of tar forced up into them by the pressure of the gas from the *working* retorts*. This would probably in no case exceed three feet: I have made it five feet in the engraving, which is perhaps unnecessary.

DD are the bonnets, to be removed when the pipes require clearing, jointed by putty and pasteboard, as just described; they are represented in Fig. 11.

Fig. 11.



E is the "hydraulic main," running the entire length of the retort-house, over

* The dip-pipes now spoken of belong to the retorts "thrown off."

the benches, in a perfectly horizontal direction, and sufficiently high up to allow of head-room, and to be removed from the flame issuing from the retorts while charging. They are sometimes turned the reverse way to that shown in the Plate, and made to rest upon the brickwork of the benches; but this is inconvenient when the brickwork has to be taken down or repaired.

This main is three-quarters of an inch in thickness, and cast in convenient lengths, contrived to reach over two benches; in this case they would be equal to thirteen feet six inches. The joints are made with iron cement. Its use is to cut off the communication between the retorts, when one or more benches are charging or open. Being half full of tar, the gas evolved from the retorts in action remains in the upper part, and the ends of the dip-pipes immersed under the surface are effectually sealed. The pressure of the gas on the surface of the tar will force some up into the dip-pipes connected with the open retorts, the height to which such tar is forced being equal to that pressure.

The diameter of the hydraulic main must be sufficient to form a reservoir capable of supplying the quantity of tar contained in the open dip-pipes without suffering it to fall below their immersed ends, and thus open a communication between the open and working retorts. There are other methods of connecting the retorts with the hydraulic main, as shown in Figs. 12 and 13.

In Fig. 12, A is the main, cast square at the bottom to allow of more tar being contained therein, and a greater facility in making the bottom joint of the stand-pipe.

B is the stand-pipe from the retort, and C the sealing-pipe covering the stand-pipe and dipping into the tar contained in the main: the annular space between the two pipes must be more than equal to the area of the stand-pipe. D is a bonnet, to be removed when the pipes require clearing. This arrangement has a neat appearance, and is economical; but its great disadvantage is the difficulty of cleaning the hydraulic main between the stand-pipes.

Fig. 13 is a contrivance for placing the hydraulic main under the firing floor. This can only be used in a few instances where the retorts are set singly or in couples, and where a coke cellar is built. It is very simple however, and in the cases just quoted may be adopted with advantage. A is the main; B is the dip-pipe, connected to the retort by an elbow-piece jointed on to the mouth by a flanch or a socket, as usual; C is the bonnet, by removing which both dip and elbow may be cleared.

Fig. 12.

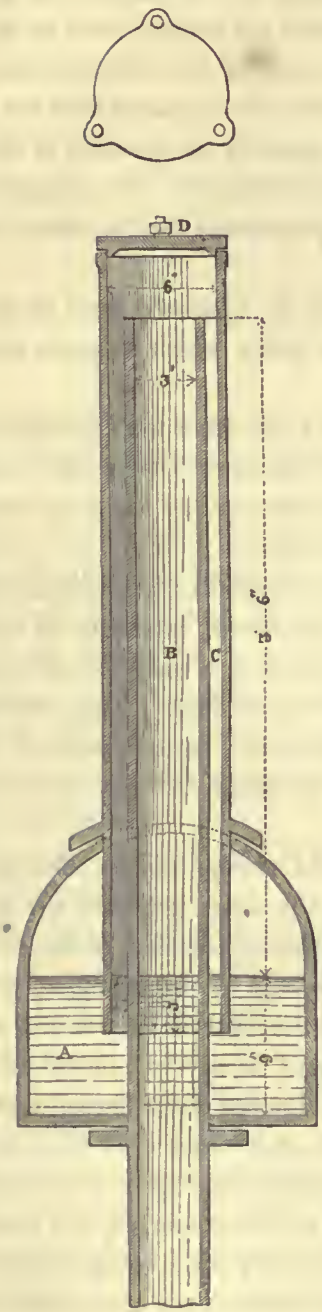
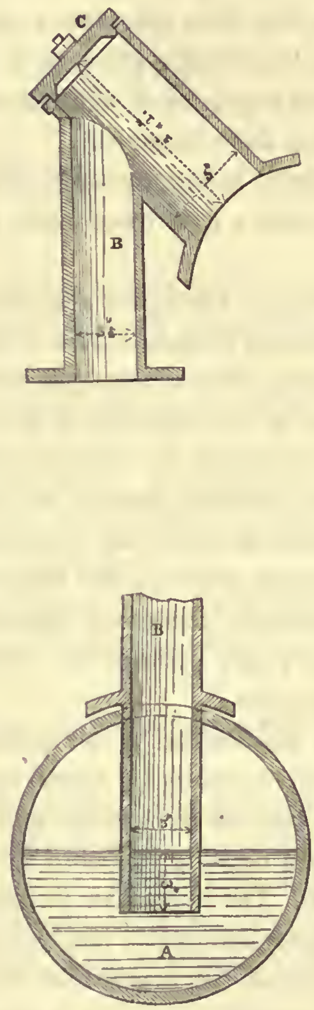


Fig. 13.



In the general arrangement of the hydraulic main two things must be observed. First, the diameter must be sufficient to supply at least twenty inches perpendicular head of tar to each dip-pipe, without causing the general level to fall below their immersed ends; and secondly, the lower part of the circumference of the pipe, which conveys the gas to the condensers, must be so placed that the tar may always be kept from rising too high, and either choking the free exit of the gas or increasing the working pressure of the retorts unnecessarily. The diameter of the main in the engraving is eighteen inches—amply sufficient for the fifteen branches of retorts as there arranged.

F is a light, hollow, cast-iron pillar, supporting the hydraulic main in the centre of each length; it is based upon the cast-iron girder which supports the firing-floor.

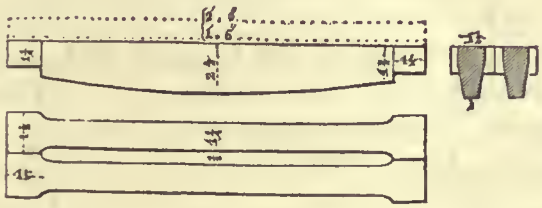
G is the pipe through which the gas makes its exit from the hydraulic main to the condensers, furnished with a slide-valve to disconnect the mains at each side of the house, when at any time it may be found requisite to repair or clear them. (The detail of the slide-valve is given in Plate XIX.)

H is a small pipe for conveying the surplus tar formed in the hydraulic main to the tar-well situated beneath the firing-floor; its lowest extremity is sealed, by being immersed in the tar contained in the well, or in a small vessel by the side and connected with it; the latter is the most convenient. This surplus pipe is not absolutely necessary, because the siphon at the bottom bend of the first stand-pipe would perform its duty, but it is advisable to draw off the tar as soon as possible.

In the construction of retort-houses, I should always advise (although it is not thought necessary by many) a coke vault to be built, provided the funds are sufficient, both for convenience and for the comparative comfort of the stokers; I have given a drawing in Plate IX. which will explain the arrangement of all the brickwork. The firing-floor is raised upon flat 9-inch brick arches over the coke vault, high enough to give head room, a space about twenty-four inches wide being left in front of the benches for the coke to fall through when drawn from the retorts: it should be of such a material as will not be injured by frequent blows. In Plate I. it is shown as constructed of Yorkshire landings; some prefer cast-iron, but either will do equally well. The flat arches supporting the floor spring from cast-iron girders fixed at one end in the brickwork of the benches, at the other in the wall of the retort-house. The distance between the centre and centre of these girders is 6 feet 9 inches.

L is the furnace for heating the retorts: its breadth is 14 inches, the length of the fire-bars 24 inches: they are represented in Fig 14.

Fig. 14.



The bars are placed loosely upon the bearers, and must occasionally be "clinkered," or lifted from their seat in the front and cleared from the slag which adheres to them.

MM... are side openings, three inches square, left in the brickwork, through which the heat of the furnace passes.

NN... are $4\frac{1}{2}$-inch walls, built of Newcastle fire-bricks, one between each of the openings M; they serve to support the fire-tiles T, on which the outside lower retorts rest. The direction of the flues is shown by arrows.

PP are fire-bricks, placed on end, and a fire-lump, upon which the two upper retorts rest. The heat acting on these being somewhat moderated, no guards of fire-tiles are necessary.

OO are openings, 3 inches by $4\frac{1}{2}$, in the crown of the main arch communicating with the branch flue.

Q is the branch flue, one being built over the centre of each bench of retorts.

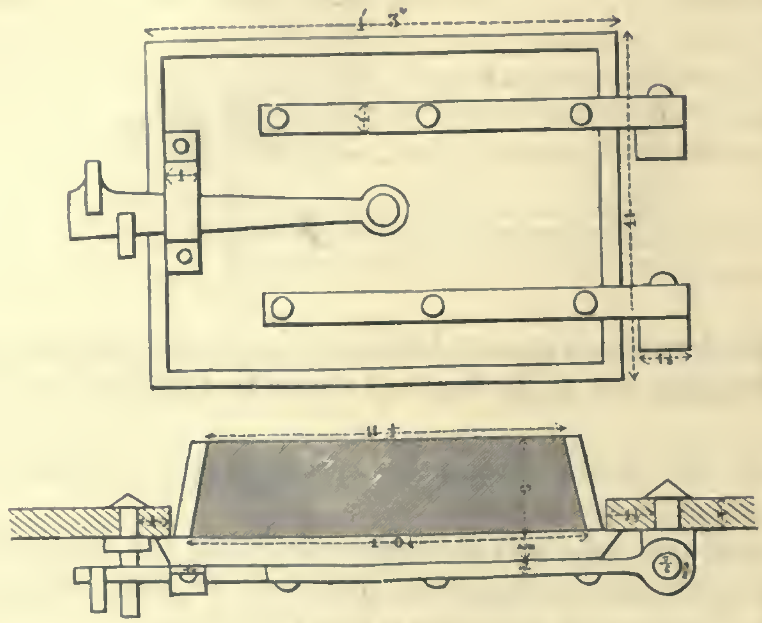
R is the main flue, running the entire length of the benches, and connected with the chimney into which all the branches lead. Between this main flue and each branch is a damper, Z, to regulate the draught through the furnaces.

S′S′... are cast-iron plugs, covering sight-holes, through which the heat of the retorts is seen and judged of.

V is the furnace door, protected by a fire-lump inside, as shown in Fig. 15.

W is a cast-iron plate, $1\frac{1}{2}$ inch thick, on which the fire-door is hinged, serving also to protect the face of the brickwork which it covers. In the centre, and about six inches above the fire-door, a square opening is cast, for the admission of an iron spout, when it is required to burn tar.

Fig. 15.



X is a pan at the bottom of the ash-pit, for evaporating ammoniacal liquor, and the offensive unsaleable liquid products which cannot be disposed of otherwise.

YY are openings left in the walls N, by which the carbon deposited from the furnace is cleared away.

I have stated that everything depends upon the heat at which the retorts are worked. It must be obvious that the durability of the distillatory apparatus greatly depends on the manner in which the heat is applied to effect the decomposition of the coal contained within the retort. If the heat be very intense, the whole vessels are rapidly destroyed; if it be too languid, the distillation is protracted, the gas is of inferior quality, much fuel, time, and labour are wasted to no purpose, and the retorts are speedily deteriorated, as the heat acts upon one part more than upon another. The experiments by which the present plan of heating retorts was arrived at, were many and expensive. Originally they were built in brickwork singly, and heated by flues passing beneath and over them, without any guard, except in some instances that of an iron saddle. They were afterwards placed in pairs, then in a

greater number; but nevertheless, until the guard of fire-tile was used, the wear and tear was enormous.

The great obstacle to working more than two retorts to one furnace evidently arose from the difficulty of conducting the heat by means of flues around the series of retorts in such a manner that it should act with equal force on all. Different workmen constructed these flues in different ways: in short, the forms varied in every possible manner, and still with the same result. Mr. Rackhouse, in the year 1815, constructed a set of retorts on the oven-plan now generally adopted, and to that gentleman solely are we indebted for the contrivance. The fuel required for heating the retorts, when set without guards on the previous plan, was less by nearly ten per cent. than that required for the same purpose on the oven-plan; but the greater duration of the retorts much more than compensated for the additional fuel. I do not mean to assert that the first construction by Mr. Rackhouse was so perfect as the arrangements adopted in later years; every invention is gradually improved upon, but his *principle* has not been altered; the later improvements are only modifications, pointed out by experience, and rendered necessary by circumstances which the greatest foresight could not anticipate.

The oven represented in Plate I. is one of the latest arrangements. The heat from the furnace passes through the square openings M at each side, and is thus equally divided along the whole length of the retorts; from between the walls N it rises between the fire-tiles at the outer sides of the lower retorts. The flame is not suffered to impinge upon any part, but is equally distributed throughout the oven, and consequently the retorts work and "burn out" evenly. The lower retorts, which would otherwise be exposed to a more direct heat, are carefully guarded by fire-tiles, which at the same time prevent the bottoms from bulging. The openings O at the top of the main arch act more in the manner of safety-valves than flues, serving to regulate the final exit of the heated air, and, being distributed along the outer length, they do not draw the flame to one part.

The whole interior of the oven, as well as those parts in contact with the flame, must be constructed of Newcastle fire-bricks set in Newcastle clay. The main arch, six feet in span and half a brick in thickness, is formed of bricks moulded on purpose to suit the curve, the joint being kept as close as possible. As this arch is permanent, much care should be taken in its formation.

A bench of retorts on this plan, if well and regularly used, ought to last from twelve to fourteen or even fifteen months, and ought never to be suffered to become cold. The first portion of oxide which forms upon the surface, when allowed

to cool, cracks and falls off, leaving a new surface to be acted upon the next time it is heated.

When it becomes necessary to reduce the number of working retorts on the approach of summer, those that are nearly burned out should be selected; or, if there are none in this condition, "let them down" very gradually, by keeping the damper closed after the fire is raked out: it will be a week before they become quite cold. The same precaution should be taken in "getting up" the heat—opening the damper gradually.

When a bench of retorts is newly set, the green work must be suffered to get quite dry before any fire is lighted.

The following is a detailed estimate for taking down and resetting a bench of five D retorts, including the main arch.

	£.	s.	d.
5 D retorts, each weighing 13 cwt., at £7. 10s. per ton	24	7	6
1 Man, jointing mouth-pieces and pipes, 3½ days at 5*s*.	0	17	6
300 Square Newcastle fire-bricks at 10*s*.	1	10	0
150 Arch ditto	0	15	0
25 Split ditto	0	2	6
12 Fire-tiles, at 4*s*. 6*d*.	2	14	0
20 Fire-tiles, at 1*s*. 6*d*.	1	10	0
100 Pavior bricks for front, at 6*s*.	0	6	0
500 Stocks for filling bed, at 5*s*.	1	5	0
8 Bushels of lime and sand, at 7½*d*.	0	5	0
½ Ton of Newcastle clay, at 30*s*.	0	15	0
1 Labourer, taking down old retorts, clearing away, and cleaning bricks, six days, at 3*s*.	0	18	0
1 Bricklayer and 1 Labourer, resetting and finishing, six days, at 9*s*.	2	14	0
½ Cwt. of cement for joints, at 7*s*.	0	3	6
	£38	3	0

The results of a chaldron, or 36 bushels of Newcastle coal, weighing 27 cwt.*, distilled in retorts set in the manner just described, and the quantity of fuel used for the distillation, will be as follows.

* Where I have taken chaldrons as a standard quantity, I wish it to be understood that it is neither the Newcastle nor London chaldron, but a quantity weighing 3024 lbs., consisting of 36 bushels of 84 lbs. each; therefore, if required, the results can be reduced to tons by a rule-of-three statement.

Dean's Primrose.

Gas of specific gravity ·390 . .	11,700 cubic feet.
Coke of good quality . . .	1¼ chaldron.
Ammoniacal liquor	18 gallons.
Thick tar	16½ ditto.
Fine oil, 19½ oz. or	1½ pint.
Fuel of Wallsend coal . . .	6 cwt. 1 qr. 15 lbs

Liddle's Main.

Gas of specific gravity ·400 . .	11,420 cubic feet.
Coke of good quality . . .	43 bushels.
Breeze	3½ ditto.
Ammoniacal liquor	17 gallons.
Thick Tar	16 ditto.
Coke used as fuel	18 bushels.
Lime for purifying	2¼ ditto.

Wallsend.

Gas of specific gravity ·387 . .	12,000 cubic feet.
Coke of good quality . . .	43 bushels.
Breeze	3 ditto.
Ammoniacal liquor	17½ gallons.
Tar	17 ditto.
Fine oil, 16 oz.	1 pint.
Fuel, Wallsend coal . . .	8 bushels.
Lime for purifying	2¼ ditto.

The following are the products from a ton of coal distilled under the same circumstances as the above examples.

Berwick's Wallsend.

Gas of specific gravity ·400 . .	8,650 cubic foot.
Coke of good quality . . .	14 cwt.
Ammoniacal liquor . . .	12½ gallons.
Thick tar	12 ditto.
Tar used as fuel	19 ditto.
Lime for purifying	86 lbs.

Heaton's Main.

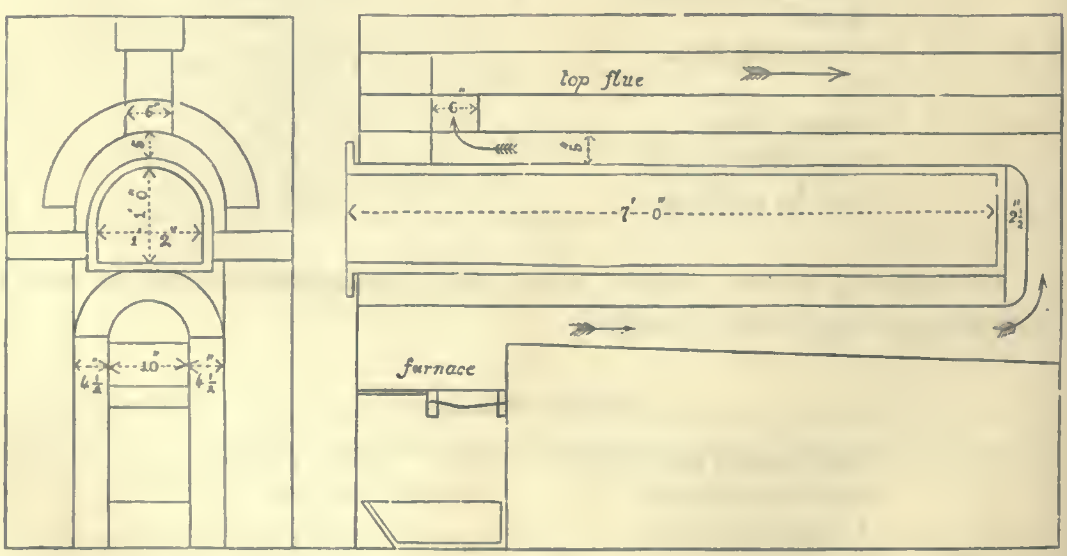
Gas of specific gravity ·390 . .	8,690 cubic feet.
Coke of good quality . . .	31 bushels.
Ammoniacal liquor . . .	12¼ gallons.
Thick Tar	12½ ditto.
Coal used as fuel	4 cwt. 18 lbs.
Lime for purifying	1¼ bushel.

Russell's Wallsend.

Gas of specific gravity ·400 . .	8,600 cubic feet.
Coke	13 cwt. 3 qrs. 14 lbs.
Ammoniacal liquor	12½ gallons.
Thick tar	11¾ ditto.
Coke used as fuel	6 cwt.
Lime for purifying	84 lbs.

In country towns, where the quantity of gas made during the winter seasons does not exceed 10,000 cubic feet in twenty-four hours, the retorts must be set singly, as represented in Fig. 16, the flue passing beneath and over the retort, which rests upon a half-brick arch, cut flat at the top to receive it; the end is guarded by a thick fire-tile.

Fig. 16.



When the quantity of gas made in twenty-four hours does not exceed 30,000 cubic feet, or when the quantity made is decreased 1200 cubic feet at a time, on

the approach of summer, the ovens may contain two retorts, as shown in the annexed woodcut. The flues are arranged in a similar manner to those in a large oven.

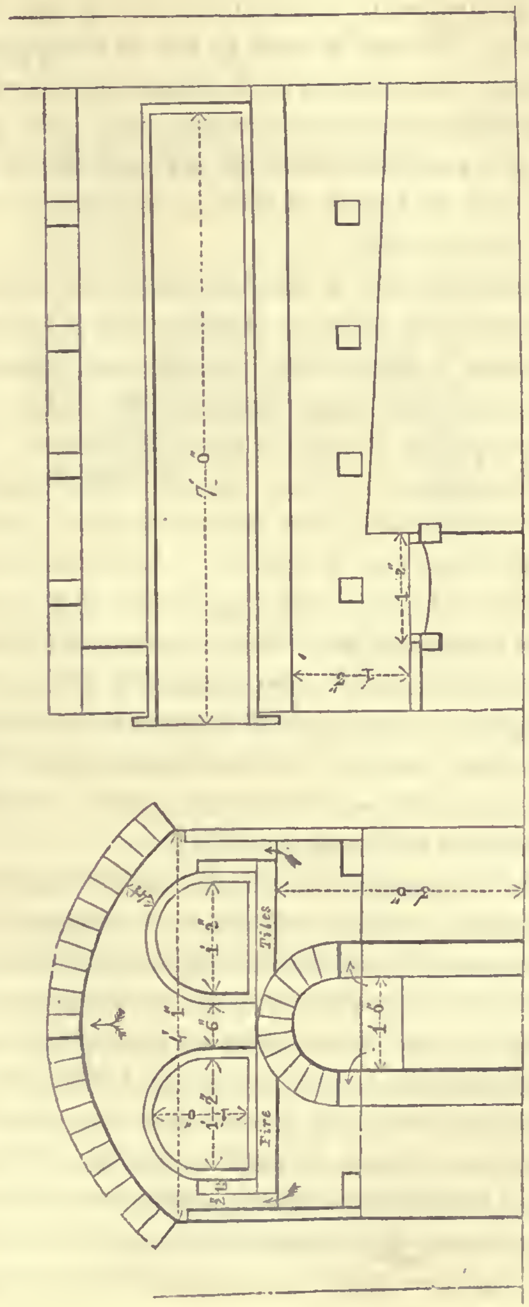


Fig. 17.

The FUEL used for heating the retorts may be either coal or coke, according to the relative value of each in the district. If coal is used, a well-regulated bench will require about 18 to 20 per cent. of the coal distilled; that is to say, to heat the retorts for the production of 12,000 cubic feet of gas, from 5 to 5½ cwt. of coal will be necessary. The use of coke as fuel is more general, particularly in those places where coal is valuable, as in the neighbourhood of London, and where coke is less in requisition as fuel for manufacturers. The quantity of coke for heating the retorts will vary from 40 to 45 per cent. of the quantity produced; that is to say, from 16 to 18 bushels of coke are requisite to distil one chaldron of coal, or 5 cwt. will distil one ton.

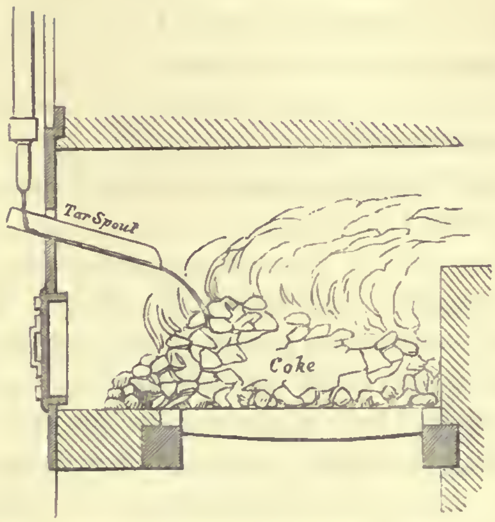
Mr. Croll, the superintendent of the Chartered Gas Company's works (Brick Lane station), has introduced a system of using coke as fuel while red-hot. The charge from the retorts is drawn into a wrought-iron carriage, and immediately taken to those furnaces which require feeding. He informs me that the saving effected by this simple process is equal to 10 or 12 per cent.: I should conceive it to be fully that. The reason is evident; because when a quantity of black coke is thrown on the previously-heated mass of fuel, the flues will to a certain extent become cool, since the heated air is absorbed. When hot coke is thrown on, no absorption takes place, and the flues are kept up at a uniform temperature.

The use of tar as fuel has of late become frequent, and is the most economical, as far as it is available. In almost every instance it is worth more to burn than to sell, viz. 3*d.* per gallon. The quantity required for carbonizing a chaldron of coal varies from 24 to 27 gallons. At the Pancras station of the Imperial Gas Company each bench of retorts will carbonize about 60 bushels of coal in 24 hours, with from 40 to 45 gallons of tar as fuel.

The furnace used for burning tar is the same as that used for other fuel, and is fed by a small continuous stream, conducted by a wrought-iron service-pipe, from a tank placed on the top of the retort-benches, on to a sheet-iron spout projecting a few inches outside the furnace-plate, and into the furnace itself, as shown in Fig. 18, where it spreads over a "breeze-bottom," previously brought to a red-heat. At Galashiels Mr. Kemp uses a small force-pump for supplying the furnaces with tar, by which means the heat is kept up with great regularity.

When retorts have been at work for some months, their interior surfaces become incrusted with a hard carbonaceous deposit, approaching, in some of its properties, to plumbago; in process of time carburet of iron and the more infusible parts of the coke form a thicker crust, which it becomes necessary to remove, both to pre-

Fig. 18.



vent the destruction of the retort, and to allow the fuel to have full effect upon the coal contained within. This was formerly effected with great difficulty by crowbars, the force required often increasing the evil it was intended to remedy.

It was afterwards found, that leaving the retort open, and allowing cold air to come in contact with the heated interior, the deposit contracted, and could be broken away in about twelve hours without danger to the retort.

Mr. Kirkham, the engineer to the Imperial Gas Company, in order to take off this crust without endangering the retorts, employs an air-blast, which is both speedy and efficacious in its operation. His method of conducting the process is as follows:—A cast-iron pipe, about three inches in diameter, is carried along the front of the benches, at a little distance above the upper retorts; at points in this pipe, directly over every retort, a screw and plug is attached, into which screw, when the plug is removed, a wrought-iron service, about an inch in diameter, can be fixed, and led into any open retort. The main pipe is connected with a blowing cylinder, worked by the steam-engine, so that a strong blast can be made to impinge upon any part of the hard incrustation, which gradually yields to it, and may then be removed without difficulty.

PLATE III.

EAR-SHAPED RETORT.

As an example of an "ear-shaped" retort, I have taken those which were at work at Mr. Clegg's iron-works near Liverpool.

Fig. 1 is a front elevation of a bench containing three retorts.

Fig. 2 is a section taken transversely.

Fig. 3 is a longitudinal section through the centre of the arch.

Fig. 4 is a plan through A B in Fig. 2.

Figs. 5, 6, and 7, are views of a mouth-piece on a scale of an inch to a foot, which will show the method usually adopted for securing the lid in all ordinary retorts; this plan I do not think has been at all improved since Mr. Murdoch first used it in 1805; and as it is simple and effective, I see no reason why it should be altered. There may have been a solitary instance of alteration for the sake of having something new, such as the bar through which the screw passes being made to turn on a hinge at one end, and secured by a latch at the other, or the screw made to act on one side of the retort mouth, etc., but none of these plans are so cheap or durable as the old one.

The great objection to the ear-shaped retort is, that the bottom bends are liable to become filled up with hard carbon, and when that is the case they are sure to crack. The principle on which they are constructed is good; and if they could be charged properly, viz. with a stratum of coal from 3 to 3½ inches thick, evenly spread over the bottom, they would be found to make more and better gas than York Ds and circular retorts (where the stratum of coal is thicker), simply because it would be more evenly acted upon. In all cases, with the same degree of heat, the thinner the stratum of coal the better the gas.

The mode of setting these retorts may be precisely similar to that explained in Plates I. and II.

PLATE IV.

BRUNTON'S PATENT.

Fig. 1 represents a front view of a bench of four retorts, upon Mr. Brunton's principle.

AA . . are the retort-mouths, the lids of which are fitted with stuffing-boxes,

for the reason to be presently described, and permanently jointed in their places with iron cement.

BB . . are hoppers, capable of holding from 20 to 28 lbs. of coal, which when an air-tight slide-valve C is drawn back, falls into the retort through the neck D: the valve is closed immediately.

E is the furnace, projecting beyond the face of the brickwork in which the retorts are set.

FF . . are handles for working a piston contained in the mouth-piece A.

Fig. 2 is a transverse section of one half of a bench. The retorts G, shown as circular, may be varied in form if thought necessary. I believe the patentee gives the preference to those of a D shape.

E is the furnace; the direction of the flues are shown by arrows.

Fig. 3 is a longitudinal section through the centre of the furnace.

H is a short pipe, open to the interior of the retort, sealed at the lower end by dipping into water, through which, after a charge is thrown into the retort from the hopper B, a portion of coke is expelled, by advancing the piston contained in the mouth-piece.

I is the pipe by which the gas, as it is formed, passes to the hydraulic main.

K is a bonnet, to be taken off at any time when required to examine the interior of the retort.

Fig. 4 is a back view of Fig 1.

Fig. 5 is a plan below the retorts. (The same letters refer to corresponding parts in all the figures.)

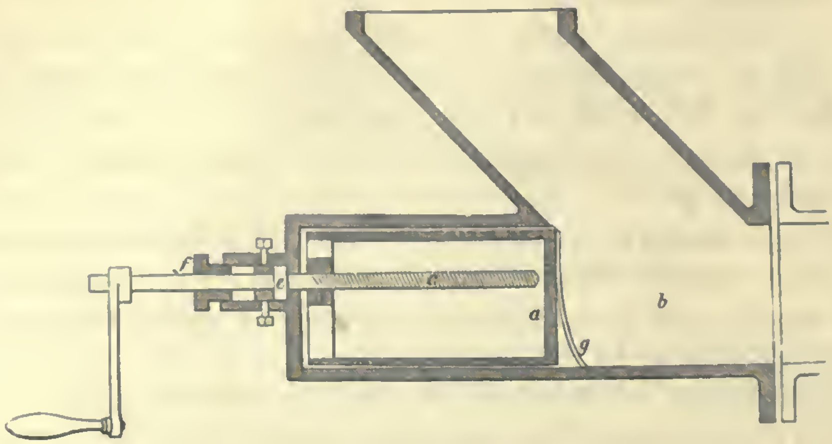
The annexed diagram (Fig. 19) will explain the construction of the piston before alluded to.

a is the piston, drawn back in the proper position to receive a charge, which, when the slide-valve is opened, will fall into the space *b*, and be propelled forwards into the heated part of the retort by turning the screw *c*, which works in a nut *d* on the back of the piston.

e is a collar upon the shaft of the screw, working between the bottom of the stuffing-box and a washer held in its place by four pins. The stuffing-box is made tight in the usual way, by screwing the gland *f* against a gasket.

g is a shield loosely attached to the front of the piston, to prevent the accumulation of small coal-dust in the mouth of the retort. When the charge is thrust forward, the piston is turned back directly into the mouth, to preserve it from the action of the heat.

Fig. 19.



That part of the retort adjacent to the flues only is heated, consequently the only part liable to much wear and tear.

Estimate of a bench of three Retorts fitted complete.

	£.	s.	d.
Three retorts fitted complete, with mouth-piece, feeder, discharging shoot, etc.	51	0	0
Brickwork and labour	35	0	0
Hydraulic main, stand-pipe, etc.	5	5	0
Furnace-doors and grate-bars	4	10	0
	£95	15	0

The only part requiring renewal is that of the retort situated between the outer walls of the bench, and weighing about 9 or 10 cwt. The fuel required to carbonize the coal is about 25 per cent. in coal on the quantity distilled.

I subjoin a letter which I have received from Mr. Brunton, fully explaining his views on the subject:—

"*West Bromwich Gas-Works*, 5*th November*, 1840.

"Dear Sir,—Agreeably to your request I herewith send you a statement of my reasons for adopting the form and principle of my patent retort; in the first place, the particular form and arrangement, and, secondly, wherein I am induced to expect a greater quantity of gas from the coals so introduced, carbonized, and discharged.

"It will be seen by reference to the drawings that the arrangements are so widely different from the ordinary form of retort, that scarcely any comparison exists. The external appearance does not present so wide a contrast as in the mode of working them, which by

considerable experience has proved satisfactory, not to me alone, but to those who have watched and calculated their operation, and found the saving to be 30 per cent. of labour and tools, with 35 per cent. more gas from the same quantity of coals.

"In describing the apparatus and its working, it is necessary to state that to the mouth-piece of my retorts is fixed a slide-valve C, according to the drawing, through which the coal is introduced into the retort, over which, upon a frame, is placed a hopper B, capable of holding one charge of coal, say from 20 to 28 lbs., so that when the valve is withdrawn the charge drops into that part of the mouth-piece in front of the piston; the valve is again closed: this part of the operation never exceeds six seconds of time. The object of the piston is to push forward the coal which has fallen into the retort, to make room for another charge. The piston is propelled forward by a double-threaded screw, which is worked through a stuffing-box at the end in the middle of the lid, to prevent the escape of gas.

"The retort is charged once every hour, or oftener, according to the quality of the coals that are used and the heat of the retort. This is one feature in the improvement of these retorts, that by varying the times of charging, with the other necessary duties requisite you may increase or decrease the quality of the gas produced to any density or illuminating power, with less labour and more practical correctness than by any other retort in use·

"It will be observed, that in the operation of forcing forward a charge of coal, a quantity of coke will be discharged into the water-cistern at the *wider* end of the retort, to which is attached a close shoot H, through which the coke drops into the cistern, and is taken out of the water by a rake or shovel, or endless chain, with a little contrivance.

"Being in the habit of using South's Staffordshire coals, which swell in a certain ratio during the process of carbonization, and agreeably to the proportion of their enlargement I have increased the area of my retort, that no obstruction should take place in the passage of the coke.

"I would here observe, that it is necessary to the correct working of these retorts that the quality of coal with respect to its enlargement should be considered in making the retorts, to secure the easy discharge of the coke and prevent breakage, etc.

"Another advantage in this retort is, that its being open at each end and the charge having to pass directly through it, there is no deposit of carbonaceous matter, which is an evil in the ordinary retorts which is attended by much inconvenience and destruction, and which has yet in no case been remedied or rather prevented. The patent retorts, after working twelve months, have been taken down and found quite free from any incrustation.

"I have now gone through the form and arrangement of the patent retort. From its simplicity, and the saving of labour, time, and tools—as no rakes or iron barrows are required, and the fuel must be reduced in proportion to the size of the ovens and the retorts, and the conducting principle of the material for heat—it must be obvious that very considerable saving must be realized.

"I shall now proceed to show what I consider to be the chemical advantages that my retort possesses over the ordinary retort; that 35 per cent. more gas can be made by it

from the same coal and in the same time. In the first instance, it is well known to all who are acquainted with gas-making in the ordinary way, that when coal is introduced into a retort at a bright red heat (the best for the production of gas), the first products that pass up the exit-pipe are moisture, with a volume of small particles of coal; and the atmospheric air that had gathered in the retort from the interstices between the coal just put in composes the mere undecomposed vapour, which is inflammable for a very considerable time after the retort is closed; this vapour, when the coals begin to ignite, forms the constituent parts of the tar and ammonia, the atmospheric air passing into the gas during forty minutes in an ordinary-sized retort. The greatest part of the product is composed principally of tar, rich with naphtha and ammoniacal liquor, that distils over with the gas, and that of a poor quality, the gas being only produced from that part of the coal which touches the red-hot retort, the body of the coal not yet being sufficiently ignited to decompose the products issuing from their interior; and it is not until the pieces of coal become charred on the exterior surface that the matter which they are disengaging becomes a gas fit for illumination.

"Comparing the above process with that of the patent retort, the advantages cannot but be obvious; the coals being introduced at one end and the gas and carbonized coke discharged at the other, it is very palpable, that all the particles, of whatever kind, disengaged from the newly-introduced coal must pass over the red-hot coke and undergo a more perfect decomposition than it is possible on the ordinary plan, and thus the tar, naphtha, and ammoniacal liquor are 50 per cent. less than from the common retort, which I have repeatedly proved by experiment, and am daily confirmed in the truth I have here advanced by the working of not less than fifty retorts in the West Bromwich gas establishment.

"The rationale on which I ground the above process is as follows; viz. the naphtha and tar (carbon and hydrogen), the water (oxygen and hydrogen), and the ammonia (hydrogen and nitrogen), are all evidently decomposed to a certain extent. The oxygen is taken up by the coke, forming carbonic acid, which is again taken up by the lime in the purifying process; the nitrogen, with the carbon of the tar, forming cyanogen, whilst the hydrogen unites with another portion of carbon and forms carburetted hydrogen.

"It will thus be seen that about 50 per cent. of the products of the distillation, which are condensed in the hydraulic main and carried off with the gas to the condenser in the ordinary retorts, are by my patent retorts productive of 35 per cent. more gas, and having it entirely in your power in the course of two hours to change the quantity and quality of the gas with the least possible trouble, which is an advantage that cannot be accomplished by the ordinary process in less than five times that period.

"This I believe to be quite correct, and without dissimulation, or advancing any opinions but what my experience leads me to think are true,

"I remain, etc.,
JOHN BRUNTON."

"To Samuel Clegg, Jun., Esq.,
London."

PLATE V.

RECIPROCATING RETORT.

The arrangement represented in this Plate is the invention of Mr. George Lowe.

It has been stated by Mr. Brunton, that the first portion of vapour produced by coal when undergoing destructive distillation in ordinary retorts will, when converted into gas, form that of the most brilliant quality, and it is to effect this that the following arrangements have been patented. As the opinion of Mr. Lowe on such matters stands amongst the highest in the kingdom, it may be taken in this case without hesitation.

Fig. 1 is a front elevation of two pairs of retorts. A^1, A^2, A^3, A^4 are the retorts; BB . . the stand-pipes; C^1, C^2, C^3, C^4 slide-valves for opening and shutting off the communication between the retorts and hydraulic main; D is the hydraulic main.

Fig. 2 is a back elevation of the same bench of retorts; EE are pipes, by which the interiors of the retorts are connected; F^1, F^2 are slides for closing that connection when required.

Fig. 3 is a plan of the lower pair of retorts. The operation is as ollows:—Supposing the entire bench to be at the requisite heat for decomposing the coal, and that they are working six-hours' charges, the lids of the retorts A^1 and A^3 are removed, and by means of scoops (each half the length of the retort) the coal is introduced at both ends, and the lids immediately secured in their places: the slides F^1 and F^2 are opened, and C^1 and C^3 closed. The bituminous vapours that rise first will pass through the pipes E E, and thence through the entire length of the hot retorts A^2 and A^4, and be converted into gas, which will pass to the hydraulic main by the stand-pipes on which the slide-valves C^2 and C^4 are fixed, and which remain open. When the distillation has gone on for half the duration of the charge—viz. three hours—the valves C^1 and C^3 are opened, F^1 F^2 shut, and the gas evolved from the retorts A^1 and A^3 passes through the stand-pipes attached to them. The retorts A^2 and A^4 are now charged, the mouths closed, the valves F^1 and F^2 again opened, and C^2 and C^4 shut. The operation is now reversed, the first vapours passing through the two first-charged retorts until their charge is expended, when C^2 and C^4 are opened, F_1 and F^2 closed, and the charge drawn.

They are then immediately recharged, and the operation of opening and closing the valves repeated.

The working doubtless appears complicated, and I must unquestionably acknowledge this method to be so. None of these valves however formed any part of Mr. Lowe's original patent; they are an addition, and certainly not an improvement. Retorts on this construction have been for some months at work at the Pancras station of the Imperial Gas Company, and I believe are found to act well, producing gas of average quality and in greater abundance than by the ordinary method. The reason of the gas being only of an average quality is, that the carburetted hydrogen made after the production of bituminous vapour has ceased still passes over the red-hot surface of another retort and deposits some portion of its carbon, the rich gas formed by the conversion of the bituminous vapour only serving to make up the deficiency.

If, instead of having only two retorts in a set, the number could be increased to six, and after the first hour the gas be allowed to pass away on the ordinary plan, then, I think, both the quantity would be augmented and the quality improved.

By Mr. Lowe's own arrangement the complication of valves is done away with, and the chance of deposition of carbon from the after gas is decreased, owing to the reduced length of the retort, and consequently the diminished area of heated surface over which the gas has to pass. The annexed woodcut (Fig. 20) exhibits the plan proposed by him in his specification, from which the following extract is taken:—

"As regards my improved mode of working off the charge, I make use of retorts about twice as long as those commonly used in coal-gas works, and I prefer them made of wrought iron, about half an inch in thickness, and that the transverse sections of the retorts should represent the forms shown in the drawing*. The retorts are open at each end, and have a mouth-piece attached to each by the usual means. These mouth-pieces are each fitted up with stand-pipes, to which are fitted, as usual, bridge-pipes, dip-pipes, and hydraulic mains, care being taken only that one of the dip-pipes B^1 does not seal or dip into the tar or liquid of the hydraulic main so far as does the dip-pipe B^2; and this shorter dip-pipe is furnished with a cup-valve, or stop-cock M, capable of so closing this dip-pipe by means of the lever N, as to force the gas, when required, to escape out of the dip-pipe B^2.

"Any number of retorts found most convenient may be set up in one oven or furnace, to constitute a setting of retorts.

* The form of section here alluded to is shown in Plate V.

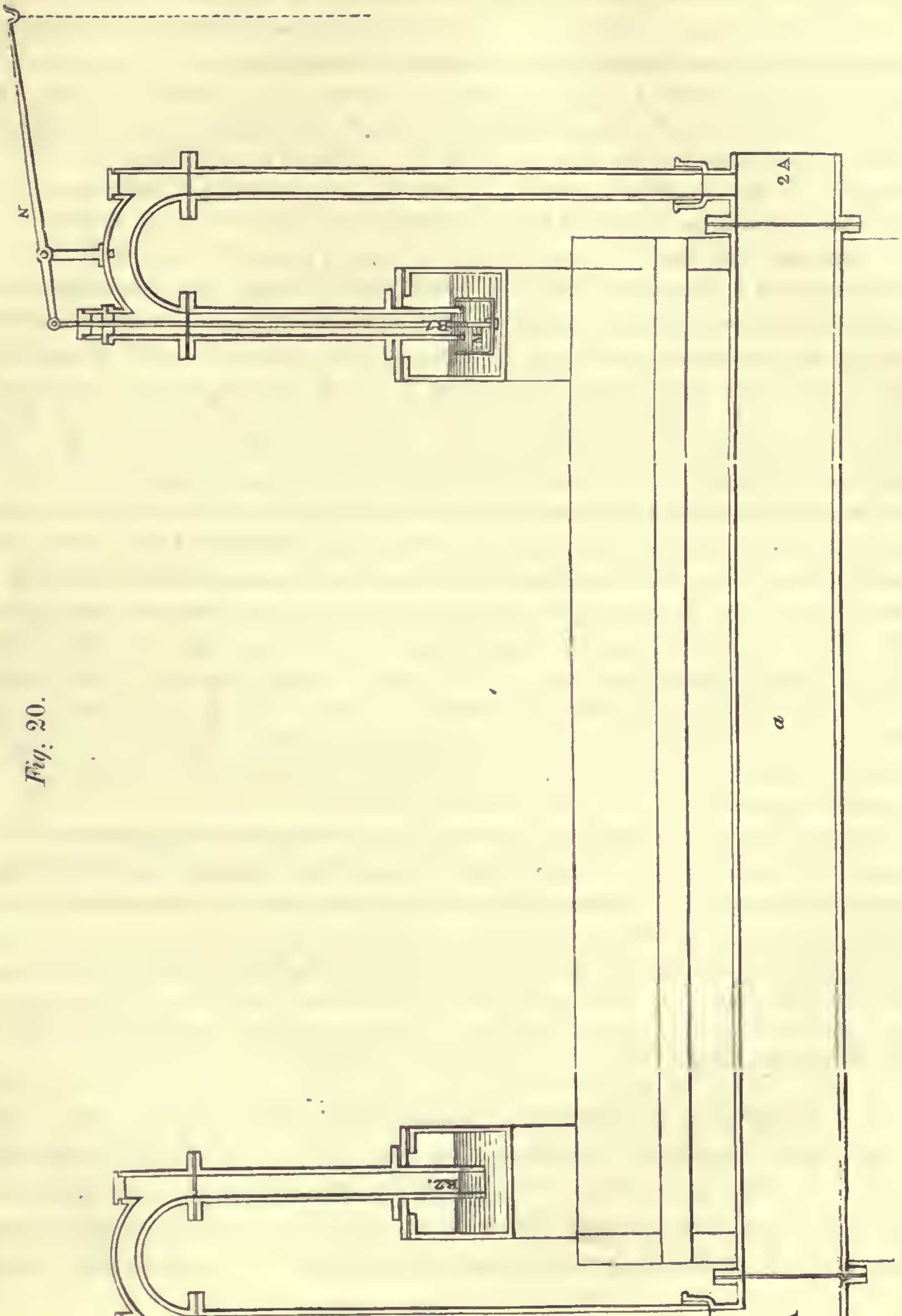


Fig. 20.

"I will now describe the mode of operating with retorts so arranged.

"Instead of putting the whole charge of coals in at one time, and taking off the gas at one end or mouth-piece only of the retort, my plan is as follows:—

"Supposing the retort 1 A 2 A to be empty, I charge only one half of its length, or thereabout, say from 1 A to *a*, and leave the valve M down or open, as shown in the Figure, in order that the gas may pass out at B^1, and receive the additional heat of the remaining or empty part of the retort. It will be seen that the gas must necessarily take this course, because the seal B^1 is not so deep as the seal B^2. When in this position (supposing the charge to be an eight-hours' charge), then at the expiration of four hours the end 2 A of the retort should be opened, and the empty half of the retort from 2 A to *a* should be charged with coal and closed with coal as usual. The lever N should then be acted upon so as to draw up the cup-valve M close to the mouth of the dip-pipe B^1, which cup, being deeper than the seal at B^2, will stop the gas from continuing its course out at B^1 and oblige it to pass out at B^2, thus compelling the gas evolved from the fresh portion of coal to traverse over and through that portion which was first put into the retort, whereby a combination is effected between the gas arising from each portion at the expiration of eight hours from the commencement of the operation; the lid 1 A of the retort is taken off, and that part of the charge between 1 A and *a*, which we must imagine to be now nearly exhausted of its gas, is to be drawn or cleared out, and a fresh charge of coal put in, and the lid replaced. At the same time, the cup or valve attached to the dip-pipe B^1, which was before lifted up or closed, must now be lowered or opened into its original position, in order to make the gas escape at B^1, thus causing the gas from the fresh charge of coals to traverse between *a* and 2 A in like manner as it formerly traversed between *a* and 1 A, and with the like effects. These alternate operations are continued every four hours, and therefore I call my retort so arranged a Reciprocating Retort.

"By this routine the gas and vapours of the earlier hours of the charge will combine and mix with those produced from the later hours, whereby much more and better gas is produced than by any process now adopted, whilst the quantity of coal-tar and of ammoniacal liquor usually formed are both much reduced.

"If it should be desirable to make gas from coal-tar with these retorts, I introduce an iron pan containing tar into the mouth-piece of each retort at the time of its charging with coal; and it is only necessary further to observe, that if the charge be a six-hours' charge, the alternations will be every three hours, and so on."

This arrangement is unattended with the danger that might arise from neglected valves on the first-described plan, there being only one hydraulic seal instead of three slide-valves. The loss of gas, from having to open the retort to draw and recharge one half whilst the other half is at work, will be trifling; for the whole operation does not occupy a minute, and the coal at that period

of its distillation and in that time will not produce more than four cubic feet of gas, which will be the full extent of loss.

The practical benefits that will arise from the adoption of this plan can only be ascertained from experience; but, judging from the talents and chemical knowledge of the inventor, I expect the results to be favourable.

PLATE VI.

REVOLVING WEB RETORT.

This retort is arranged so that the coal is acted upon in a thin stratum, and converted into gas at once: the chemical advantages of this method are many; —all the elements of the coal are liberated at nearly the same time, and unite with one another in such proportions as to form gas of the best illluminating quality, and in greater abundance than when the coal is carbonized in mass. The condensed bituminous vapour which forms tar in the ordinary process is by this nearly all converted into olefiant gas.

Fig. 1 is a longitudinal section through A B in Fig. 3.

Fig. 2 is a transverse section through C D in Fig. 1.

Fig. 3 shows end views, with the drum and stand-pipes.

Fig. 4 plans of the retort in section, over the top of the retort, the web and furnace, respectively.

Fig. 5 is an enlarged view of the drum.

The same letters refer to corresponding parts in all the Figures.

E is a hopper containing the coal; F is the discharging-disc; G is the retort; H is a web on to which the coal is discharged by the disc F; I I are the revolving drums carrying the web H; K is the furnace; L L the flues passing under and over the retorts, and finally into the main flue; M the shoot into which the coke falls; the end of which may either dip into water, or be furnished with a tight door.

The retort itself, and the chamber in which the drums work, are made of wrought-iron boiler-plates, riveted together so as to be quite gas-tight. The only parts subject to wear and tear are the retort adjoining the flues and the web, both of which are heated; the latter however never becomes so hot that the shape alters. The action of this arrangement is as follows:—

All the coal must be either ground, or beaten small and screened, so that no lumps remain larger than coffee-berries, and a twenty-four hours' charge must

be thrown into the hopper, and secured by a luted cover. The discharging-disc, which is nine inches in diameter, with six arms, is made to revolve uniformly with the drum below it, at the rate of four revolutions an hour; for this purpose two shafts run the entire length of the retort-beds, on one of which the drums are fixed; on the other are the discharging-discs, connected at one end by a strap. The diameter of the hexagonal drums is so regulated, that the coal which falls on the web from the discharging-lip will at one revolution have passed the entire length of the retort. Fifteen minutes is quite time enough to convert the coal so distributed into gas. Each link of the web is 14 inches long and 24 inches broad, having a surface of 336 square inches, upon which the contents of one partition of the disc will be discharged, viz. a little more than 124 cubic inches of coal in a stratum less than three-eighths of an inch thick. Each successive link receives the same quantity, so that, in one entire revolution of the disc and drum, 745 cubic inches of coal (equal to 21 ℔s.) are distributed over a heated surface of 2016 square inches, and converted into gas.

Eighty-four pounds of Wallsend coal will by this process make 450 cubic feet of gas of the specific gravity ·490. It therefore follows, that in 24 hours 18 cwt. of coal will be discharged by each retort, making 10,800 cubic feet of gas, equal to 12,000 cubic feet per ton.

These retorts are considerably more expensive in the first instance than those in general use, but in the end they would be found cheaper. Indeed, the entire arrangement is one of great economy, and by far the most scientific process yet adopted for making coal-gas: it requires no attendance, except that of keeping up the furnace, and charging the hopper once in twenty-four hours. No gas is lost, and no tar made. The coke produced is increased in quantity by about 75 per cent., but its quality is not so well fitted for general purposes (although superior for culinary uses) as that produced by the common process.

The power employed for turning the shafts may be a water-wheel, which would be preferable to a steam-engine, unless in large works, where the latter could be employed for other purposes. The tank from which the water would flow on to the wheel may, in cases where there is no natural fall, be filled by a hand-pump. An overshot wheel, six feet in diameter and nine inches in breadth of float, would drive twelve retorts at the speed required; the water for turning such a wheel for twelve hours may be pumped up by two men in about an hour and a half.

The following is an estimate of the cost of four retorts as shown in the engraving, exclusive of brickwork:—

	£.	s.	d.
Four wrought-iron retorts, each weighing six cwt. at 25*s*. . .	30	0	0
Four chambers of No. 9 plate, riveted and made tight . .	35	10	0
Hoppers, four in number, to contain eighteen cwt. of coal each, fitted with a water-jointed lid at the top	25	0	0
Eight revolving drums, to drawing, with shafting, turned bearings, and stuffing-boxes complete	27	15	0
Four webs of plate-iron connected by links of $\frac{5}{8}$ round iron, as shown in the drawing	5	5	0
One wrought-iron tank, running the entire length of the bed, for receiving the coke	8	4	0
Eight large doors and fittings	7	6	6
Fire-door, grate, and bearing-bars	2	5	0
	£141	5	6

This estimate will appear large when compared with the prices given for common retorts; but the debtor and creditor accounts of the two methods, compared together at the end of twelve months, will be found much in favour of the above.

The quantity of gas produced by five D-retorts, such as are shown in Plate I., will be about 14,000 cubic feet in twenty-four hours, of specific gravity ·390 or ·400, and the quantity produced by four of the proposed retorts will be 43,200 cubic feet in twenty-four hours, of the specific gravity ·470 or ·490.

At the end of fifteen months, or when a bench of ordinary retorts is worked out, they may be replaced for £38. 3*s*., as stated at page 70. And supposing the wear and tear of the proposed retorts to be the same, at the end of fifteen months they would require to be replaced also, which would be done for about £43. 18*s*. All the machinery, except the retorts and webs, will last for years without any repair, except what may arise from contingencies, to which all machinery is subject.

The minor advantages attendant upon this form are, that it occupies less space; the stokers (so called at present) might be spared that name; the heat would not be felt more than in a boiler-house, and the retort-house might be kept perfectly clean, wholesome, and free from suffocating vapour.

The web may be repaired at any time, or even made in the first instance by a labourer. After it has been at work some time, the plates of which it is formed, by their contact with carbon at a red heat, become converted into excellent steel, and might be sold for a sum at which a new web could be constructed.

If I were to become the lessee of any gas-works, I should undoubtedly use this

plan, being quite confident that the extra expense of their first erection would be more than returned to me at the end of the first year.

It is well known to every one connected with the manufacture of coal-gas that a thin stratum is desirable. Chemistry will point out the various causes and effects, and I have already shown that the quantity of tar and ammoniacal liquor is much increased when the coal is acted upon slowly, as the centre portion *must* be when decomposed in mass. By the means just described, the conversion of the vapours and rich products of the coal is properly effected, and no deposition of carbon takes place, as the gas passes away immediately on its formation. These advantages, combined with the saving of tools and labour, will fully justify my statement of the advantages attendant upon this form.

EARTHEN RETORTS.

In speaking of clay or earthen retorts, it is necessary to limit my remarks upon them to the *results of practice;* for in many instances, owing to actions not entirely and clearly accounted for, the results given by these vessels differ from those which *theory* in its strict sense would admit as being correct.

Several manufacturers of clay retorts exhibited in the Exhibition of 1851. The following is taken from the 'Reports of the Juries,' page 584, and is valuable on account of the disinterestedness with which it must have been written :—

"Messrs. JOSEPH COWEN and Co., of Blaydon Burn, Newcastle-upon-Tyne, are exhibitors of samples of fire-clay, fire-bricks, and patent fire-clay gas-retorts, which are all of admirable quality, and bear the highest reputation; the jury have therefore awarded a prize medal to them.

"The use of fire-clay is not of very ancient date, and has greatly increased within the last few years. It is found in England almost exclusively in the coal measures, and from different districts the quality is found to differ considerably. The so-called 'Stourbridge clay' is the best known, and will be alluded to presently; but other kinds are almost, if not quite, as well adapted for the higher purposes of manufacture, being equally free from alkaline earths and iron, the presence of which renders the clay fusible when the heat is intense. The proportions of silica and alumina in these clays vary considerably, the former amounting sometimes to little more than 50 per cent., while in others it reaches beyond 70, the miscellaneous ingredients ranging from less than 1½ to upwards of 7 per cent.

"The works of Messrs. Cowen and Co. are among the most extensive in England, and they obtain their raw material from no less than nine different seams, admitting of great and useful mixture of clay for various purposes.

"After being removed from the mine the clay is tempered by exposure to the weather, in some cases for years, and is then prepared with extreme care. The objects chiefly made are fire-bricks and gas-retorts; the latter being now much used, and preferred to iron for durability.

"These retorts were first made by the present exhibitors in ten pieces (this being twenty years ago), and since then the number of pieces has been reduced successively to four, three, and two pieces, till in 1844 they were enabled to patent a process for making them in one piece, and at the present time they are thus manufactured of dimensions as much as ten feet long by three feet wide in the inside, which is however more than double the size of the largest exhibited by them*.

"Gas-retorts of very fair quality are shown by Mr. RAMSAY, of Newcastle, who has also succeeded extremely well in the manufacture of fire-bricks. The retorts show a little more iron than is desirable, but the exhibitor has been considered worthy of honourable mention. Retorts of less creditable appearance are exhibited by Messrs. HICKMAN and Co., of Stourbridge, and Mr. A. POTTER, of Newcastle. The surface of both these retorts is cracked and undulating. When we consider the high and long-continued temperature to which these objects are exposed, the absolute necessity of attending to every detail in mixing the clay and moulding the retort will be at once recognized, and the apparently slight defects of some of those sent for exhibition require to be noticed as of real importance.

"Next to England, the finest specimens of fire-clay goods, on a large scale, are from Belgium. The gas-retort sent from France is not remarkable for excellence."

I think it may fairly be considered as established, that clay retorts, made in one piece, or of several pieces so perfectly jointed as to be absolutely tight, are, after two or three weeks' work, more economical than iron retorts, to the extent of about 1*d.* per 1000 cubic feet of gas from the same coal. When first set to work, the clay retorts are porous, and the loss of gas is often very considerable: it has

* "There are now (January, 1851) at work at the South Metropolitan Gas-works, Old Kent-road, two benches, with five clay retorts in each, which have been uninterruptedly in action for upwards of seventeen months: they are ⌓-shaped, twenty inches wide by twelve and a half inches high, and seven feet long, and are calculated to have produced up to the present time at least 1,800,000 feet of gas per retort, with an expenditure of fuel *not exceeding* that of the iron retorts used on the same station, and there is every prospect of each retort making upwards of 2,000,000 feet of gas before it is worn out. These excellent specimens of clay retorts are made in one piece, and were manufactured by Messrs. J. Cowen and Co."—*Journal of Gas-lighting, January* 10, 1851.

been suggested to charge them repeatedly with breeze and tar, to glaze them internally before using them for distillation; and this may probably be advisable when practicable; after a week's working they however become pretty tight by their pores being filled up with the carbonaceous matter formed by the decomposition of the richest portions of the gas, which matter, as in iron retorts, accumulates afterwards, and forms in time a thick coating, especially under careless management. The deposition of carbon is greater in clay than in iron retorts, because they are worked at a higher heat, and the gas should be removed from them by an exhauster as fast as it is made, to prevent its becoming excessive. It is also, especially when an exhauster is not used, advisable to allow them to remain uncharged, with their lids off, for a day or two every six weeks, that the admission of atmospheric air may break down the deposit.

One practical point must be observed, that clay retorts of small dimensions are less economical than those of larger size, owing to the greater per-centage of fuel required to keep them at a proper temperature. The advantage of using the latter description of distilling-vessel is simply a question of profit and loss, or whether it is cheaper to *burn iron or coal.* The material of which they are formed is a non-conductor of heat, consequently the absorption of caloric is less rapid; and although they retain their heat when a fresh charge is introduced better than iron retorts, yet not sufficiently to bring down the quantity of fuel as low as that required for metal*. Notwithstanding this, even small clay retorts are preferred in many places, particularly in Scotland. Mr. James Reid, of the Montrose Gas-works, has favoured me with the following description of his earthen retorts:—

"We have had clay retorts in operation for the last three years, and from the great difference in price, compared with that of iron retorts of the same size, and from the immense superiority over metal in working them, we have entirely given up the use of the latter. I tried the clay retorts in the shape of an ellipsis, in the D and circular form, and find the cylindrical to be the best adapted for carbonizing the coal effectually. The size I find best adapted to all purposes is eight feet long, fourteen inches diameter, and four inches thick: such a retort costs at Inverkatling or Clackmannan £2. 6*s.*; the pillars or columns for supporting them are 6*s.* each, and each retort finished costs £3. 4*s.* The mouth-pieces are cast metal, and fastened to the end of the retorts by bolts and flanches, as in the ordinary description, and jointed with fire-clay and iron cement. The retorts

* Some who advocate clay retorts make out that they require less fuel than iron retorts, and moreover that they make more gas. I apprehend their chief economy arises from the one fact of their greater durability.

are made in two lengths, and are jointed by a body of fire-clay well diluted with water. The most economical plan for erecting them is to set them three under one arch, heated by one fire. Their only drawback is, that when the heat is let down they contract unevenly on cooling, and are liable to leak when again required for distillation; they generally last two years."

Clay retorts have been used for some years by Mr. Eunson at Wolverhampton with success, the cost of material for setting an oven being under £2. The retorts are circular, and made in joints of thirty-two inches long. In several places these retorts are made at the works.

Of clay retorts, or ovens on a large scale, I have given two examples. The first is that of Mr. Grafton, the second that of Mr. Spinney, which is decidedly inferior in every respect to the former, both from its greater thickness and number of joints, and from its incomplete setting. The quantity of fuel required by each for decomposing the coal will be stated hereafter.

The first idea of adopting fire-clay as a substitute for metal in the construction of retorts occurred to Mr. Grafton in the year 1820, when he took out a patent for the invention; the first of them erected in this kingdom was at the manufactory of Messrs. Butcher, in Wolverhampton. This retort was of the square form, but it was soon afterwards altered to the oven, or D-shape, which form has been adopted ever since, as shown in the engraving; large numbers having been put up under his direction in different parts of this kingdom and in several towns on the Continent.

The reader will fully understand their plan of construction from the elevation and sections in Plate VII., which require no description, except that I may remark that the bottom is exposed directly to the heat of the fire, and is slightly "cambered," or curved upwards, to enable it with more certainty to retain its form. The cement with which the parts of the oven are jointed is a composition which Mr. Grafton has been at much pains to render perfect, but he has not favoured me with the materials of which it is formed. It seems to be an excellent substance, and when the interior is coated with it, becomes vitrified and quite gas-tight under considerable pressure*.

* "*Cement for the joints of clay retorts.*—For jointing the mouth-pieces, take 20lbs. of gypsum, and make it into a pulp with water; add to it 10lbs. of iron borings, saturated with a strong solution of sal-ammoniac. Mix the whole well together till it is of a consistency fit for use. For the joints between the separate lengths of clay retorts the proportions must be varied to 10lbs. of gypsum and 20lbs. of iron-borings treated in the same manner."—*Journal of Gas-lighting, May* 10, 1852.

During the first seven years after their introduction great prejudice and opposition from interested bodies existed against the plan; and to such an extent did this proceed, that in one of the principal gas-works of the metropolis, where six of the largest ovens of this description were set up at a great cost, a plot was almost simultaneously laid for their destruction, which soon produced the effect desired by the contrivers. The same fate attended two similar retorts erected at Montpelier, where they were wilfully destroyed. It is but justice to add, that the Directors of both Companies afforded Mr. Grafton every advantage and facility for a fair trial, and in the first instance offered a large reward for the discovery of the persons who had designed and occasioned the loss. I mention this as one example out of many, to show that new inventions, however valuable, which profess to make great changes, rarely meet with encouragement in the first instance. As a further proof of this remark, I may notice the long time lost before the immense advantages offered by the Meter to gas companies were acknowledged or appreciated. At Manchester, one of the most enlightened towns in the kingdom for mechanical and chemical science, this valuable instrument was for a long time expressly forbidden to be used, although five years afterwards the Directors were compelled to acknowledge that the great success of the Manchester works was chiefly attributable to the Meter.

In England and Scotland the fire-clay retort has superseded the use of metal in no less than forty towns*; in some instances it has lasted for the extraordinary period of twelve years; while, during this time, at all other works where the invention is not yet used, it may be asserted that iron retorts have been renewed as many times. The oven or D-shaped retorts are found to be the most advantageous, being made with a capacity to carbonize one cwt. of coal every hour. They can be constructed either to be heated by coke ovens, or coke furnaces, or by the burning of tar: with coke ovens they are more durable. It appears that clay retorts, when constructed upon such a scale as that given in the Plate, have great power to *retain* their heat when brought to the proper temperature for decomposing the coal, and the introduction of a fresh charge is not nearly so much felt by them as by metal; this is a *practical* point—one which I have been at much pains to ascertain, and which I would not state were I not convinced of its correctness by personal observation. Mr. Grafton afforded me every facility for experiments, and is willing to do so to all who have a desire to test his retorts. This power of re-

* The use of clay retorts has much increased since this date (1841); hardly *any* town in Scotland uses iron retorts.

taining heat is proved by constant practice to produce 1000 cubic feet of gas per ton from the same coal more than the average of the London produce, and the consumption of fuel is not more than 22 or 23 lbs. of coke to carbonize 100 lbs. of Newcastle coal, taking the average of six months' working: it is even less with the Staffordshire or Lancashire coal.

When properly constructed, these retorts are not in any degree liable to fracture or to the escape of gas, but are of such strength as to resist the greatest pressure which is likely to be put upon them. The coke also made by them is invariably of better quality, and produces less breeze or waste.

The advantages of the fire-clay retorts, combined with their great durability, will ere long be generally acknowledged, and their use will consequently be more extensive. At the gas-works in Cambridge, where from the beginning this kind of retort has been adopted in every variety of form, no retort has been changed nor any new one erected for four years. The oldest in that establishment, which have been in operation upwards of seven years, remain perfectly sound, and continue as efficient for making gas as on the first day they were at work.

At my request Mr. Grafton has favoured me with the following account of the cause of carbonaceous deposit in retorts:—

"After a series of experiments established in 1839 at the Cambridge Gas-works, and after having in vain offered a large premium for the discovery, I was myself enabled to detect the origin of the great accumulation of the carbonaceous deposit in coal-gas retorts, as well as the means of obviating an evil which has been the source of so much loss to the manufacturers of gas. Previously to that period the most eminent scientific authorities consulted on the subject considered this accumulation as the result of high degrees of heat and too great an extent of heated surface.

"To ascertain how far this opinion was correct, I commenced my experiments with a number of retorts reduced to various lengths, by the ends being filled up with brickwork, the other dimensions remaining unaltered.

"By this difference of length, after repeated trials and at various temperatures, the deposit did not appear to be diminished, although it did not accumulate so rapidly; and finally it formed a coating of the same substance, not less in a short retort than in a long one.

"It was observed in all cases that the substance began to form itself first at the closed end of the retort, whence it gradually advanced and accumulated in bulk; at that end the coal (especially with cylindrical iron retorts) is carbonized first; hence the inference is, that the best constituents, viz. the hydro-carburets, being without the means of escaping, become decomposed, leaving as a result the carbonaceous deposit.

"I then had two retorts constructed with an ascending pipe to carry off the gas at each

end, so that its stream might divide itself into equal portions each way, thus reducing its passage over the heated surface from seven feet (the length of the retorts) to three feet six inches, and affording equal means of escape to the gas from all parts of the coal. The deposit after three months of constant working was considerably less at the closed end of the retort; but it formed itself in the same quantities on the roof, and soon covered the whole of the inner surface, gradually, as heretofore, diminishing the capacity of the retorts and increasing the consumption of fuel.

"The resistance offered to the gas during these experiments by the purifiers and the weight of the gas-holders was equal to a column of water of nine inches by the gauge on the mouth-piece; this pressure having varied by the alteration of the weight of the gas-holders between winter and summer. I remarked that the accumulation was not so rapid in the summer months, when the resistance was less and the gas less compressed. I immediately had the pressure increased to a column of fourteen on the gauge, keeping up the usual heat. The retort for this experiment, like all the rest, was constructed of fire-bricks of the oven form, seven feet nine inches long, five feet wide and sixteen feet deep, capable of holding and carbonizing 130 lbs. of coal every hour, or seven cwt. in six hours. At the end of the first week the deposit appeared about an inch in thickness, and when once formed it accumulated more rapidly till the whole inner surface within a foot of the mouth was covered with it: at the further end it rapidly filled up the retort, preserving an equal thickness, until, at the expiration of two months, it had reached 24 inches in thickness, stopping up the retort quite one-fourth of its length. Under the roof and upon the sides of the remaining portion of the retorts, it formed a coating of not more than two or three inches thick; in four months more it would have filled up the whole.

" We then had the substance cut through into two parts, and taken out; when, after allowing for some of the scattered fragments, it weighed full 10 cwt. 24 lbs.

"The coal carbonized during the time of this experiment was 67 tons of Woodside Wallsend, the same having been used in nearly all the former trials; the deposit therefore was in weight about $1\frac{8}{10}$ per cent. of the coal carbonized, *and undoubtedly occasioned by the compression of the gas in the retort* immediately after its formation.

" I have applied myself to the means of taking off the whole of the pressure, which I effected, excepting only the resistance offered by the half-inch dip in the fluid of the hydraulic pipe. Under this change of operations, after the same retort was again worked with the Wood-side coals without interruption for four months, I had the satisfaction of observing that scarcely any deposit appeared at the expiration of that time.

" If I mistake not, this will prove a welcome discovery to all Gas Companies, more especially to those where the Newcastle coal is used*."

* The pressure being removed, the gas escapes from the hot retort more rapidly, and the olifiant gas is not deprived of its carbon to such an extent.

PLATE VIII.

SPINNEY'S BRICK RETORT.

Fig. 1 represents a front elevation of the brick retort and hydraulic valve of Mr. Thomas Spinney, of the Cheltenham Gas-works.

Fig. 2 is a transverse section through the furnace.

Fig. 3 is a longitudinal section through the centre of the oven and the flue.

A is the retort or oven. The bottom and sides are formed of Newcastle fire-tiles; the crown of fire-bricks is composed of Stourbridge clay, mixed with about 10 per cent. of sharp river-sand and pipe-clay, which addition prevents the bricks from cracking, and improves them in other respects. The interior dimensions of the oven are three feet two inches wide, eight inches to the springing-line of the arch, and from thence to the crown six inches.

The fire-bricks just spoken of, which compose the crown of the oven, and also the fire-tiles which form the bottom and sides, are made with a groove round the jointed edge, into which the fire-clay with which they are set is compressed, this serving effectually to keep the ovens gas-tight.

B is a cast-iron plate secured against the front of the oven by wrought-iron bolts, built into the general brick-work at *a a* . . and jointed with a channel running round the mouth of the retort, as shown at *b b*, Fig. 3. When heated, this joint is slightly compressed by the expansion of the oven against the plate; for the rods by which it is secured, being comparatively cold, will retain their original length, and consequently prevent the advance of the plate.

C is the mouth-piece, bolted on to the cast-iron plate B, and jointed with iron-cement in the usual manner. The lid, being considerably larger than those used on ordinary retorts, is secured by two screw-bars, S S, Figs. 4 and 5, and when removed is supported by a small crane T turning in a socket cast on to the side of the mouth-piece.

D is the furnace communicating with the flues F F through the openings E E . . The arrangement will be sufficiently explained by the engraving.

G is the stand-pipe, furnished at its upper end with an hydraulic valve. When the retort is in action, the lever H (Fig. 6) is acted upon, and the cup I raised above the surface of the fluid contained in the larger cylinder, so that the gas passes away by the outlet-pipe K without being obstructed in the least degree. When the charge has to be drawn, the cup is let down into the position shown in the figure, sealing the stand-pipe by a head of ten inches.

The reason assigned by Mr. Spinney for the use of this kind of valve, instead of the ordinary hydraulic main, is that the retort may not be exposed to any pressure; and as the charge is only drawn once in twelve hours, the inconvenience of having to *attend* this valve is not felt as formerly when used with iron retorts.

L L . . are plugs covering sight-holes, through which the heat of the flues and oven is examined.

The first cost of the erection of one of these ovens, complete, is £90,—the annual wear and tear is about £5.

The usual charge for these retorts is five cwt. of Welsh coal, from which Mr. Spinney informs me he can produce 2400 cubic feet of good gas in twelve hours. The quantity of coke obtained from a ton of coals is from fourteen to fifteen cwt.

The fuel required for heating the retort is 50 per cent. of coal on the quantity distilled. If coke be used as fuel, three-fourths of the quantity made is necessary. This large quantity is owing to the incomplete setting and the unnecessary thickness of the retort itself; and if we allow that an increase of 1000 cubic feet of gas may be obtained from a ton of coal by distilling it in a brick oven instead of an iron retort, we shall arrive at the following costs by each process.

One bench of five large York Ds will carbonize two tons of coal in twenty-four hours; each ton will yield, say 8000 cubic feet of gas, with ten cwt. of coal as fuel.—

	£.	s.	d.
Two tons of coal, at 20*s*. per ton	2	0	0
Fuel 25 per cent.	0	10	0
Wear and tear of retorts for 24 hours	0	2	6
Cost for 16,000 cubic feet	£2	12	6

which is equal to nearly 3*s*. $3\frac{1}{2}$*d*. per thousand.

Two brick ovens will carbonize the same quantity, viz. two tons in twenty-four hours, and produce, say 9000 cubic feet of gas from each ton, with one ton as fuel.—

	£.	s.	d.
Two tons of coal, at 20*s*. per ton	2	0	0
Fuel 50 per cent.	1	0	0
Wear and tear of ovens	0	0	6
Cost of 18,000 cubic feet	£3	0	6

which is equal to nearly 3*s.* 4¼*d.* per thousand; giving three farthings per thousand in favour of iron retorts.

CROLL'S METHOD OF SETTING RETORTS.

Figs. 20a and 20b represent a method of setting retorts patented by Mr. A. A. Croll in 1843. This plan is stated to effect economy in fuel of from 40 to 60 per cent., economy in the decreased wear and tear of retorts, and a saving of labour and space. The peculiarity of this method consists in combinations of clay and iron retorts. The heat as generated, whilst at its highest intensity, acts upon the clay retorts and then descends into the chamber below upon the iron retorts before it passes into the main flue, the clay retorts being thus exposed to the immediate action of the heat, instead of iron ones protected by fire-lumps or brickwork.

Fig. 20a is used in the largest class of works; Fig. 20b in works of medium size.

Fig. 20a.

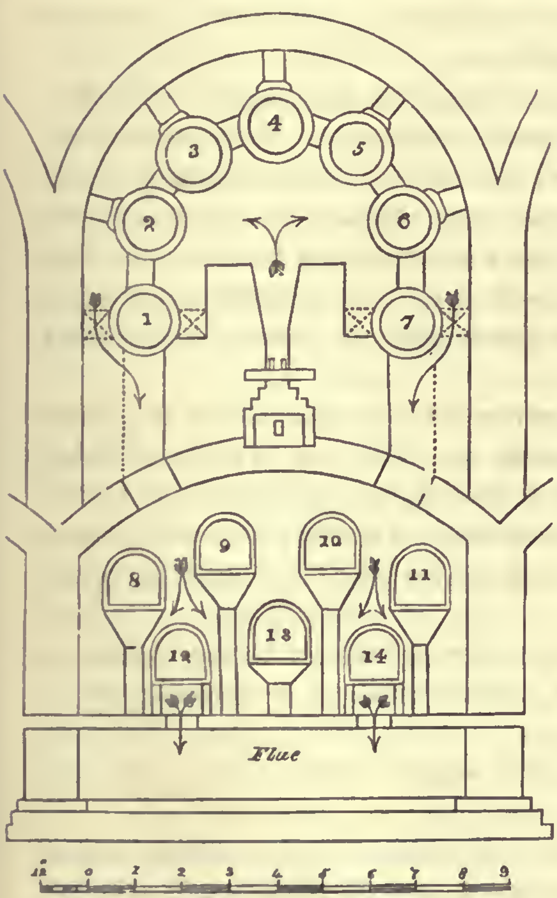
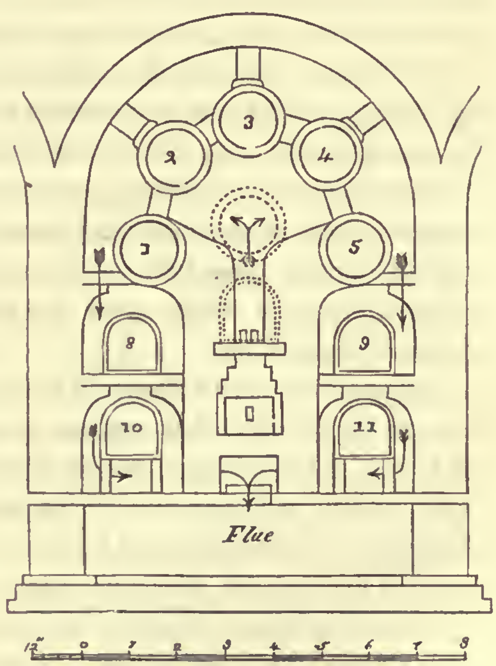


Fig. 20b.



ON THE MANUFACTURE OF HYDROCARBON GAS.

The present arrangement of tho apparatus for this process is defective in some points of detail, especially in the water-retorts. This is incidental to all new manufactures; and as the theory of the hydrocarbon process is undoubtedly correct, there can be little doubt that ultimately such modifications will be introduced as will render the manufacture as certain as that of ordinary gas-making.

The engravings (Plate VIII. *A*) show a setting of three hydrocarbon gas retorts in one oven, each retort having an internal area of about sixteen cubic feet, and the bed of three being capable of producing about 14,000 cubic feet of gas per diem. The retorts used for hydrocarbon gas are of various sizes, shapes, and lengths, to suit existing ovens, quantity of gas required, etc.

The setting and flues are similar in every respect to those adopted in the case of ordinary retorts, and any number of retorts which may be found necessary can be placed in one oven. They differ from the ordinary coal-gas retort by having a horizontal plate or diaphragm cast in the centre, dividing the retorts into two compartments, or chambers, and going within about one foot from the back, thus leaving an open space between the chambers equal to the sectional area of either chamber, through which space the gas passes from one chamber to the other during carbonization.

Although the retorts shown in the engraving are D-shaped, with the diaphragm cast in horizontally, they are not necessarily so. They may be made cylindrical and with the diaphragm cast in a vertical position, or long retorts open at both ends without a diaphragm. When the diaphragm is cast in a horizontal position however, it is slightly arched, so as to counteract the tendency of the plate to sink from its own weight, after much use.

These diaphragms are found in practice to have the effect of bracing the retorts, and resisting that tendency to a lateral expansion which is so destructive of D-shaped retorts generally.

The water-gas retort is similar in every respect to the cannel retort, both being cast from the same patterns.

In the arrangements before us, either one water-gas retort may be worked into two cannel retorts, or two water-gas retorts into one cannel retort, as is best

suited to the quality of the material used, or of the gas required. The former is effected by having the dips into the hydraulic main equal, by which means the pressure is alike in the retorts B and B′, and one-half the volume of water-gas generated in the retort A enters the lower chambers of each by the connecting pipes G G; the latter is effected by shutting off one of the stand-pipes by a plug or valve, by which means the water-gas generated in the other two retorts is made to discharge itself into the lower chamber of the third or cannel retort. When very rich carbonaceous materials are used, either three or more water-gas retorts can be arranged to discharge the gas generated therein into the retort in which the hydrocarbon material is being distilled. This may be effected by connecting the mouth-pieces of the water-gas retorts with that of the illuminating gas retort, the water-gas retorts being set in the same or separate ovens. Probably in large gas-works it will be found advantageous to have the water-gas retorts set in separate and distinct ovens from the other retorts, so that a different set of workmen may be told off for making each kind of gas—a system by which the best skill and management would be ensured for each department.

Before describing the advantages arising from the mechanical as well as the chemical operations of the water-gas in its passage through the illuminating gas retort, it will be necessary to describe the mode by which the water becomes decomposed, and its constituents of hydrogen and oxygen liberated. To effect this decomposition, both chambers of the retort are well filled with either coke, wood-charcoal, burnt sawdust, or peat-charcoal. Such material can scarcely be too tightly packed in with the ordinary tools used in a gas-house; there is not however any occasion for ramming, but no space whatever should be allowed to exist between any part of the retort and the coke or charcoal, so that the greatest possible contact between the steam or gas and the incandescent carbon may be secured. If a space be left between the crown of the retort and the coke or charcoal, the effect will be, that for want of sufficient contact, an undue proportion of carbonic acid gas will be formed; and it will not be out of place here to remark that the generation of water-gas free from carbonic acid gas, is almost as much a question of contact as one of temperature.

The coke from Newcastle or other similar coal is the least suitable for the decomposition of water, from its hardness and want of porosity; the soft coke got from Wigan cannel is much more suitable, and should be broken into small pieces about half a cubic inch each before being placed in the retorts. The coke selected for this purpose should be as free from sulphur as possible, as its presence will cause the formation of sulphuretted hydrogen. The coke should be removed from the retorts

periodically, so as to keep the carbon as pure as possible, and remove any accumulation of earthy matter. Wood-charcoal, where it can be obtained cheaply, is much better for this purpose than coke, being a much purer carbon, as well as a softer and more porous material. Any accumulation of very fine charcoal-dust in the retorts is objectionable, as it is carried out of the retorts and deposited in the hydraulic main, forming with the tar a thick obstructive mixture. Peat-charcoal is found to decompose water much faster than either coke or wood-charcoal; this arises from its very great softness and porosity, and the compact form in which it lies in the retorts, thus presenting an immense heated surface to the steam or gas as it filters through.

The relative productive power of a water-gas retort charged with soft cannel coke, wood-charcoal, and peat-charcoal, is found to be in the proportion of the numbers 3, 4, and 5. The amount of carbon absorbed in the generation of a given quantity of water-gas is very small. It is known that 9 lbs. of water and 6 lbs. of carbon will make 15 lbs. of hydrogen and carbonic oxide gases in equal volumes. With these data, the specific gravity of the gas, and the weight of a cubic foot of air, we may readily estimate the weight of carbon in 1000 cubic feet of the water-gas. Thus: 15 lbs. $= 105{,}000$ grs.; 100 inches of air $= 31{\cdot}012$ grs.; $\therefore$ 1 cubic foot of air $= 535{\cdot}88$ grs.

$$\frac{15 \text{ lbs.} = 105{,}000}{1 \text{ ft.} \;\; = \;\; 535{,}88} \text{ grs.} = 195{\cdot}95 \text{ cubic feet of air} = 15 \text{ lbs.}$$

The mean specific gravity of hydrogen and carbonic oxide gas is $\left(\frac{{\cdot}0691 + {\cdot}9674}{2}\right)$ $= {\cdot}5182$; $\therefore$ 195·95 cubic feet of air at a specific gravity of 1·000 will be equal to $\left(\frac{195{\cdot}95}{{\cdot}5182}\right)$ 378 cubic feet of the mixed gases.

$$378 \text{ ft.} : 6 \text{ lbs.} :: 1000 \text{ ft.} : 15{\cdot}87 \text{ lbs.}$$

As coke or charcoal is not pure carbon, and as there will always be a loss in charging, etc., and as carbonic acid gas will be generated despite the greatest precaution, and carbon lost afterwards in purification, about 18 lbs. weight may be fairly taken as necessary to generate a thousand feet of water-gas*. The subsidence of the coke or charcoal in the retorts, consequent on the burning down of the material into a more compact state (as the absorption of the carbon by the oxygen, liberated during the decomposition of the water, proceeds) must be met by the removal of the retort-lids once in about every eight hours, and the pushing

* This applies to water-gas made by itself, and not in connection with cannel gas as in the hydrocarbon method; in the latter case much of the water-gas is found in the cannel retort from the tar: of this however hereafter.

back of the coke or charcoal, a shovelful or so of fresh carbon being put in each time, to keep the retort replenished.

There are other matters requiring attention in the management of water-gas retorts. No attempt should be made to make water-gas until the temperature of the retorts is raised to the required point, viz. a lively red heat, and the carbon is properly heated to the core, and the tubes CC imbedded therein also red hot. A neglect of this precaution will result in a deposit of water in the tubes, and the cooling of the adjacent coke or charcoal; indeed there ought not to be a deposit of water in the tubes at any time—they should be worked, so as to convert the water that enters them, into steam *immediately*.

Water-gas retorts produce most gas when worked on *four hour* charges; the stream of water, being quickest at first, should gradually diminish, until at the end of about three hours and a half it is entirely stopped off. During the last half-hour the retort will continue to throw off some gas, owing to the moisture deposited from the steam in the front part of the retort. During this half-hour also the carbon will be raised in temperature, so that at the commencement of the next charge it will generate most gas when it is most required for preserving the light-giving particles of the cannel gas, so rapidly given off at the commencement of each distillation of cannel.

The water enters the upper chamber of the retort A, flowing from the taps F in the finest possible stream or rapid drops, and, passing through the siphons D (shown in the elevation) it falls into small portable evaporating tubes CC, placed inside the retort to receive it, and convert it into steam. These tubes are nearly as long as the retort, lie flat on the diaphragm, and are imbedded in the coke or charcoal.

The mouthpiece end of each tube has a funnel opening to receive the water as it drops in, and a slit or opening to emit the steam; the other end is closed, so that no steam can escape except through the opening at the mouthpiece end.

These steam-generating tubes are found to render the temperature of the retorts more uniform and continuous; they also prevent any damage being done to the diaphragm of the retort by immediate contact with the water.

This method of passing water into the retorts, instead of steam, has many advantages: the expense of a steam-boiler and apparatus is dispensed with, and the supply of steam more accurately determined than could possibly be done were it supplied through a steam-pipe from a boiler, subject to an ever-varying pressure. Any contrivance to regulate the supply of steam to the retorts by counteracting

this irregularity of pressure would be often out of adjustment, and therefore a source of risk and insecurity, and quite out of place in a gas-house.

There would also be very great difficulty in contriving any self-acting apparatus which would diminish the supply of steam gradually towards the end of each working or charge, and shut it off at a given time. This essential requirement however is readily overcome when water, instead of steam, is allowed to enter the retort, by having a cylinder or other vessel to hold the exact quantity of water required for each charge, so regulated as to depth, that the pressure of the head will discharge the water when full into the siphon at the proper speed, and as the head is diminished by the flow from the tap, the discharge is proportionally diminished, until the vessel is empty, and the retort has had its quantum of water for the generation of the exact quantity of steam required.

To return to the description of the method by which the water-gas is produced. The steam generated in the tubes as described, passes backwards along the upper chamber, and then forwards through the lower chamber, A′, of the retort, permeating in its course through the incandescent carbon, and becoming decomposed into hydrogen, carbonic oxide, and carbonic acid gases. The proportion of hydrogen is always a fixed and known quantity; the proportions of carbonic oxide and carbonic acid gas are however variable, and dependent on the temperature used and the extent of the contact. A low temperature, or want of sufficient contact, will cause an excess of carbonic acid gas; but if the retorts are worked at a lively red heat, (a white heat is wholly unnecessary, and damages the cannel-gas more than it improves the water-gas,) and are kept well filled, the amount of carbonic acid gas generated, and not converted into carbonic oxide gas in its passage through the illuminating gas retort afterwards, will be readily removed by the ordinary lime-washer used at most gas-works.

If expense were not the most important consideration in the manufacture of this, as well as all other gases, the retorts might be worked at a very low temperature, to prevent the formation of carbonic oxide gas as much as possible. The carbonic acid gas could then be removed by a strong solution of lime and water, or caustic soda, and pure hydrogen would be left, the best of all diluents for illuminating gases, as it produces little carbonic acid gas or other impurity during combustion. It will be evident however that this mode of working, although it might diminish the charge for wear and tear, would decrease the producing power of the retorts, and increase the expense of purification considerably. The water-gas thus liberated enters the lower chamber, B, of the cannel retort (or retorts, as

the case may be) through the connecting pipes, G: these upper and lower chambers are charged with cannel or coal, through which the water-gas passes during distillation, and there exercises its valuable influence of conserving the illuminating properties of the cannel gas and increasing its volume at the same time. The conservative influence of hydrogen on olefiant gas may be beautifully illustrated by a very simple experiment. If through a tube heated to redness some of our ordinary illuminating gas be passed, it will be found to deposit carbon on the sides of the tube, and lose much of its illuminating power; but if hydrogen gas is passed in connection therewith, there will be no deposit of carbon, the light will be preserved, and the volume increased. This is one of the causes which lead to such remarkable results in the application of the hydrocarbon process to coals and cannels. Another is, that the speed at which the olefiant gas passes through the retorts is accelerated by the addition of water-gas, and the injurious contact with the red-hot metal proportionally diminished. Another and a very important cause of the increased yield is attributable to the action of the water-gas on the tar, the formation of which is to a certain extent arrested, and much of it converted into illuminating gas. The yield of tar per ton of cannel is not however so much diminished by the hydrocarbon process as might be imagined, but the exact quantity would be very difficult to determine, as it varies with the temperature at which the retorts were worked.

Dr. Frankland ascertained, by experiment and analyses, that a portion of the water-gas was generated in the cannel retort from the surplus steam which escaped decomposition in the water-gas retort; it is plain however that the slightest variation of temperature in the water-gas retort would affect the quantity by diminishing or increasing the proportion of steam entering the cannel retort. Some of the tar also is absorbed in supplying the extra volume of carbon necessary to convert carbonic acid gas into carbonic oxide gas; and this action takes place to a very great extent, especially towards the end of a working, when it is produced in the water-gas retort in a greater proportion than at the commencement, at which time the coke in the cannel retort is at a higher temperature and all the more suitable for the conversion of the non-inflammable into inflammable gas.

Another item to be taken into account in ascertaining the quantity of tar absorbed, is the volatile parts or vapours of hydrocarbons which are taken up by the water-gas, and which are one great source of the increase in light per ton of cannel obtainable by the process.

But tar is of very little value; and as one gallon of it weighs about 10 lbs.,

and 10 lbs. of gas at a specific gravity of ·600 will measure about 217 cubic feet, it will be evident that the consideration of it, however interesting, is very unimportant in a commercial point of view; in reckoning the carbon absorbed per 1000 feet of water-gas, it must however be taken into consideration in any estimate of the cost of the water-gas. The fact of a portion of the water-gas being formed in the cannel retort also affects the question of cost very materially, so that it is evident that the cost of water-gas made by itself, and the same made in combination with cannel gas, as described, will differ largely. Although it appears that a small proportion or excess of steam passing into the cannel retort is beneficial, still an undue quantity of it would be very injurious, as it would, to a certain extent, decompose the illuminating constituents of the cannel gas, converting them into non-illuminating water-gas; it would also have the effect of carrying them out of the retort, to be afterwards lost by condensation. The mechanical combination of the water-gas and the cannel gas which takes place in the cannel retort, is a permanent one; and indeed it could not be otherwise than permanent, as the constituent parts of the water-gas are also to be found in the cannel gas when made by the ordinary process.

During a series of experiments made by Dr. Frankland on this and other gases, in which they were submitted to the ice test, it was found that the gases made in this way, in connection with water-gas, suffered least from exposure to low temperatures: this is readily accounted for by the presence of a much larger proportion of hydrogen in the hydrocarbon gas. The larger proportion of hydrogen is due almost entirely to the decomposition of tar by steam; for tar, consisting of carbon and hydrogen, on being acted upon by steam, adds its hydrogen to that furnished by the water, and greatly increases the proportion of this gas.

Another cause for the excess of hydrogen is owing to the generation of a small proportion of carbonic acid gas which is afterwards removed in purification. If no carbonic acid gas were formed, the volumes of carbonic oxide and hydrogen would be equal; but this not being the case, and the carbonic acid gas being removed, the hydrogen is in excess.

In Plate VIII. *A*, A is the upper, and A′ the lower chamber of the water-retort; the course of the decomposed steam is shown by the arrows in the longitudinal section. BB are the lower chambers of the cannel retorts, into which the water-gas enters through the pipes GG; it passes to the back of the retorts, and returns along the upper chambers, B′B′, to the front, combining with the cannel gas during its progress, the resulting hydrocarbon gas escaping by the stand-pipes HH. The same figures refer to the same parts in all the views.

Report on the Commercial Advantages of White's Patent Hydrocarbon Process of making Gas from Cannels, etc. By Samuel Clegg, Esq., M. Inst. C.E.

These inquiries and calculations were undertaken with a view to render more clear to the practical Gas Engineer the commercial advantages to be derived from the adoption of White's Patent Hydrocarbon Process of making gas from coals and cannels, for the purposes of illumination; the data on which they are based are got from practical experiments made first by Dr. Frankland, and afterwards by myself, with a view to test the accuracy of his very able and voluminous report. The trials I made at Manchester, and the strict inquiries I entered into at various works in that neighbourhood at which the gas is made by this process, have fully satisfied me of its general accuracy; indeed, personal inquiry and experiment will prove incontestably to every Gas Engineer the great commercial importance of the system.

Wigan Cannel.—It is a difficult matter to determine the exact quantity and quality of the gas made from this cannel by the ordinary mode of gas-making. This difficulty arises from a variety of causes; partly from the different specimens examined by various experimenters, and partly from the form of retort and temperature used in distillation. The result however of very extended inquiries inclines me to the opinion that about 10,000 cubic feet of 20-candle gas (20 candles = 5 feet per hour) may be safely taken as the average product per ton weight. The same difficulty as to exact quantity and quality arises, as a matter of course, when this cannel is treated by White's Process, and from the same causes. The experiments however of myself, Dr. Frankland, and others, and very minute and extended inquiry, satisfy me that about 16,000 cubic feet of 20-candle gas may be obtained from one ton, on the average, by the hydrocarbon method; and further that 26,000 cubic feet of 12-candle gas may be got from a ton by the same process. The increase in volume, without diminution of light, is therefore in the first case 60 per cent.; or, if expressed in candles, one ton by the old process and one ton by the new process will produce respectively light equal to 40,000 and 64,000 sperm candles. As expressed in weight of cannel per 1000 feet of 20-candle gas, they will require respectively 224 lbs. and 140 lbs. In the latter case the increase is 165 per cent., and the quality of the gas is reduced to that of the average London gas, viz. 12 candles = 5 feet, thus yielding 62,400 candles to the ton, and requiring 87 lbs. of cannel to make 1000 feet.

Lesmahago Cannel.—This valuable cannel becomes more valuable still for illuminating purposes when treated by White's Patent Process. It is peculiarly suited for the hydrocarbon process, inasmuch as the water-gas required to preserve its large percentage of rich olefiant gas from destruction, and the additional quantity required to reduce the products to the standard of ordinary and serviceable gas, is immense. By the common process, its average product will be about 10,500 to the ton of 40-candle gas; and by the Patent Process, I ascertained by experiment that it will give, on the average, 36,000 feet of 20-candle gas, and 58,000 feet of 12-candle or average London gas, to the same weight: the comparative results expressed in sperm candles, burning 120 grains per hour,

will be respectively 84,000, 144,000, and 139,200 to the ton, and is expressed in weight of cannel per 1000 feet of gas, 213 lbs., 62 lbs., and 39 lbs. respectively. The coke is valuable, as it provides ample fuel for heating the retorts.

Boghead Cannel.—This cannel, probably the richest gas material known, when treated by the hydrocarbon method, yields 52,000 cubic feet of 20-candle gas, and 75,000 cubic feet of 12-candle gas, per ton weight; the gas produced from it by the common method is wholly unfit for domestic use from its tendency to smoke and smell. These very objections to its use however, when made in the usual way, prove its great value and suitability for the Patent Process. Its product by the old method is about 13,500 cubic feet of gas to the ton; the increase is therefore 285 per cent. for 20-candle gas, and 460 per cent. for 12-candle gas; and the weight required to produce 1000 feet of each description of gas will be respectively 166 lbs., 43 lbs., and 30 lbs. It yields a very rich tar, but its coke is unfit for fuel, and valueless; there is little or no sulphur in its composition.

The Meythell, Newcastle, and all sorts of coals and cannels, are of course suitable for this system of gas-making. But it is needless to enter upon their particular and relative value here. Those familiar with coals and cannels will be able to draw very accurate conclusions, as to their value, from the data herein contained.

Having shown the results in produce which are obtained by the application of the hydrocarbon process to Wigan, Lesmahago, and Boghead cannels, the question now arising is the expense at which these great increases of volume and light are effected; and this involves the consideration of cost of material, labour, wear and tear, fuel, purification, the cost of water-gas, and the value of the residual products of tar and coke by each system.

Cost of Materials.—This will of course vary according to locality. The prices used in the following calculations are those of London in the first instance, and local prices in the other cases. Any corrections in price, to suit any particular locality, can be readily made.

Labour.—There is clearly an immense saving per 1000 feet in this item in favour of the Hydrocarbon process. Contrast the case of three retorts worked by each method. By the old system, three will have to be charged and three drawn; whilst by the other system there will be only two to charge and two to draw; the third retort, which makes water-gas for the other two, only requires to be occasionally replenished with a small quantity of coke, perhaps a shovelful in six hours, and the water-tap is self-acting; the saving in labour is therefore fully 75 per cent. on the increase in volume.

Wear and Tear.—This item will be found to be about the same per 1000 feet in each case; or if there is a difference, it will be in favour of the hydrocarbon process—instance the three retorts alluded to worked by each method. Assume them to be capable of holding 2 cwt. of Wigan cannel each, the time required for carbonization is slightly in favour of White's Process. Now by the old process the 3 charges = 6 cwt. will produce, at 10,000 to the ton, 3000 cubic feet of gas in a given period, say 4 hours; by the new process the same retorts will produce in the same time, from 4 cwt. of this cannel, with

the addition of the water-gas at 16,000 feet to the ton, 3200 cubic feet. The diaphragm in the hydrocarbon gas-retorts bears so small a proportion to the weight of the retort itself, that it is unnecessary to take it into account, especially as it expedites the carbonization. The temperature at which the hydrocarbon gas-retorts are worked is certainly below the average. It is a universally admitted fact that the water-gas retorts last longer than the others; this has been clearly ascertained by two years' experience at Southport, eighteen months' experience at Ruthin, and shorter periods at other places—one water-retort being found frequently to last as long as two carbon-retorts. It may therefore be very safely concluded that the wear and tear is alike in each case; the probability is however that it will be found largely in favour of White's system.

Fuel.—For precisely the same reasons as those given under the head Wear and Tear, this item may be safely taken at the same rate per 1000 feet in each instance, all circumstances of setting, etc., being alike.

Purification.—This item will be found to be in favour of White's Process in nearly the same ratio as the increase in volume. The impurities of sulphur and ammonia are chargeable to the cannel gas only. The only impurity which could be attributable to the water-gas is carbonic acid gas, but no larger percentage of this gas is generated by the hydrocarbon process than by the ordinary process when coals or cannel are used—although in the case of hydrocarbon resin-gas a large percentage is frequently present. Why its presence should be detected in appreciable quantities when resin is used, and not when cannel is used, is readily accounted for by the fact that in the latter case the carbonic acid gas generated in the water-retort comes in contact with a large surface of incandescent carbon in its passage through the cannel retort, and thus takes up the extra volume of carbon necessary to convert it into oxide of carbon gas.

Cost of Water Gas.—The cost of this gas per 1000 feet, when made by itself for heating purposes, and when made in connection with coal or cannel gas, as it is in the hydrocarbon process, differs materially. In the former case the fuel and wear and tear are chargeable at nearly the same rate per 1000 feet as that for ordinary coal or cannel gas; when made in connection with coal or cannel gas, however, much of these charges are borne by the cannel gas, inasmuch as in the cannel gas retort a large proportion of the water-gas is generated. It is hardly correct however to designate the increase got by the hydrocarbon process as water-gas only, much of it being in reality got from the volatile parts of the tar, acted upon by the water-gas; the small quantity of tar absorbed being of little or no value, as the tar resulting from each process does not differ much. For these reasons, the cost of this gas will therefore be considerably less than if made by itself. The coke required to decompose the water is very trifling; the scarcely discernible quantity which disappears from the water-gas retort proves it to be a very inconsiderable item. When made by itself, as it is in many places under Mr. White's Patent, for heating and singeing purposes, it could be readily ascertained; and would no doubt prove the already well-ascertained fact in chemical science, viz. that 9 lbs. of water and 6 lbs. of carbon will make

15 lbs. of hydrogen and carbonic oxide gases in equal volumes, or about 16 lbs. of coke to 1000 feet of water-gas—certainly not more than this weight of coke and tar can be abstracted from the retorts while 1000 feet of water-gas is generating.

Another circumstance telling in favour of the low rate at which the water-gas can be produced, is the fact, that in retorts of similar size, at similar temperatures, more water-gas than cannel gas can be generated in a given period: this, in addition to the above, places the rate per 1000 feet for fuel and repairs much lower than in the case of cannel or coal-gas. To obtain therefore the exact cost of this gas per 1000 feet, a series of experiments were entered into, during which the gas was made in connection with various descriptions of cannel, and at various rates of increase. The ascertained cost of the cannel gas per 1000 feet, when made by itself, was in each case deducted from the entire cost of the mixed gases, in the ratio due to the percentage of cannel gas contained therein —the difference being in each case the cost of the increase or water-gas. The results did not differ very much. The following is however the mean result:—

Estimated cost of producing 6000 feet of Water Gas, when made in connection with Cannel or Coal Gas, as in the Hydrocarbon Process.

	s.	*d.*
Fuel	0	9
Labour	0	3¾
Repairs of retorts, mains, etc. . . .	1	2¾
Coke to decompose water	0	2½
	2	6 or 5*d.* per 1000 feet.

In small towns, mills, etc., it will be unfair to estimate the cost of the water-gas as given above. It will be considerably less, as an extra retort or two for its generation can be put into small ovens without any increase in fuel.

We have now sufficient data before us for a fair commercial comparison of the cost of 1000 feet of gas made by the old and new systems, from different materials, and of different illuminating powers. The calculations will be as follows:—

Estimated cost of producing 1000 feet of Gas from Wigan Cannel by the common process. Illuminating power 5 feet = 20 candles. Cannel, 18*s.* per ton. Coke, 4*s.* per ton.

	d.
Cannel, 224 lbs. @ 18*s.* per ton . .	21·60
Labour	3·50
Lime	0·50
Repairs of retorts, works, and mains . .	5·00
	30·60
Cr. Coke, etc.	4·00
	26·60 or 2*s.* 2½*d.* per 1000 feet.

Estimated cost of producing 1000 feet of 20-candle Gas from Wigan Cannel and Water, by the Hydrocarbon process. Cannel, 18*s*. per ton. Coke, 4*s*. per ton.

	Cubic Feet.		*d.*		*d.*
Cannel gas .	10,000	@	26·60	=	266·0
Water gas .	5,000	@	5·00	=	30·0
	16,000				296·0 or 1*s*. 6½*d*. per 1000 feet.

Estimated cost of producing 1000 feet of 12-candle Gas from Wigan Cannel and Water, by the Hydrocarbon process. Cannel, 18*s*. per ton. Coke, 4*s*. per ton.

	Cubic Feet.		*d.*		*d.*
Cannel gas .	10,000	@	26·60	=	266·0
Water gas .	16,00	@	5·00	=	80·0
	26,000				346·0 or 1*s*. 1¼*d*. per 1000 feet.

Taking the Wigan Cannel at 14*s*. per ton, and the Coke at 3*s*. per ton, the results corresponding to the three preceding items will be as follows :—

	s.	*d.*
1000 feet of 20-candle gas by old process	1	9¾
1000 feet of 20-candle gas by Hydrocarbon process . .	1	3½
1000 feet of 12-candle gas by Hydrocarbon process . .	0	11¼

Estimated cost of producing 1000 feet of Gas from Lesmahago Cannel, by the common process. Cannel, 24*s*. per ton.

	d.
Cannel, 213 lbs. @ 24*s*. per ton . .	27·40
Labour	3·50
Lime	0·50
Wear and tear of retorts, mains, etc. .	5·00
	36·40 or 3*s*. 0½*d*. per 1000.

Estimated cost of producing 1000 feet of 20-candle Gas from Lesmahago Cannel and Water, by Hydrocarbon process. Cannel, 24*s*. per ton.

	Cubic Feet.		*d.*		*d.*
Cannel gas	10,500	@	36·40	. .	382·20
Water gas	25,550	@	5·00	. .	127·50
	36,000				509·70 or 1*s*. 2*d*. per 1000.

Estimated cost of producing 1000 feet of 12-candle Gas from Lesmahago Cannel and Water, by Hydrocarbon process.

	Cubic Feet.		d.	d.
Cannel gas	10,500	@	36·40	382·20
Water gas	47,500	@	5·00	237·50
	58,000			619·70 or 10½d. per 1000.

The Lesmahago Cannel being taken at 18*s*. per ton, the results will be as follows:—

	s.	d.
1000 feet of gas by old process	2	5½
1000 feet of 20-candle gas by Hydrocarbon process	0	11¾
1000 feet of 12-candle gas by Hydrocarbon process	0	9¼

Estimated cost of producing 1000 feet of Gas from Boghead Cannel by the common process. Cannel, 28*s*. per ton.

	d.
Cannel, 166 lbs.	24·75
Labour	2·40
Lime	0·25
Fuel	4·50
Repairs of retorts, mains, etc.	3·50
	35·40 or 2*s*. 11½*d*. per 1000.

Estimated cost of producing 1000 feet of 20-candle Gas from Boghead Cannel and Water. Cannel, 28*s*. per ton.

	Cubic Feet.		d.	d.
Cannel gas	13,500	@	35·40	477·90
Water-gas	38,500	@	5·00	192·50
	52,000			670·40 or 1*s*. 0¾*d*. per 1000.

Estimated cost of producing 1000 feet of 12-candle Gas from Boghead Cannel and Water. Cannel, 28*s*. per ton.

	Cubic Feet.		d.	d.
Cannel gas	13,500	@	35·40	477·90
Water-gas	61,500	@	5·00	307·50
	75,000			785·40 or 10½*d*. per 1000.

The Boghead Cannel being taken at 20*s.* per ton, the results will be as follows:—

	s.	*d.*
1000 feet of gas from Boghead Cannel by common process .	2	4½
1000 feet of 20-candle gas by Hydrocarbon process . .	0	11
1000 feet of 12-candle gas by Hydrocarbon process . .	0	9¼

From these calculations, it will be seen that the saving which may be effected in producing gas by the hydrocarbon process is very large.

The cost of average London gas is about 1*s.* 8*d.* per 1000 feet; the saving therefore effected by making gas of the same standard of light from Lesmahago or Boghead Cannel by the hydrocarbon process is 9½*d.* per 1000 feet, an amount which will cover the average charges for fuel, wear and tear of retorts; and would realize a saving of nearly £20,000 per annum to an average London Company with an annual consumption of five hundred million cubic feet, or equal to 7 per cent. on a capital sufficient to erect works and mains for a consumption of five hundred millions per annum; or on the total consumption of London and its environs, which is about five thousand million cubic feet per annum, a yearly saving of £200,000.

It is worthy of remark that a much less working capital will be required by a company making their gas by the hydrocarbon process than one working by the ordinary method: thus, in the case of two companies having the same annual consumption, say 500 million cubic feet, using the same cannel, paying the same prices, and supplying the same description of gas—say 20-candle gas, from Wigan Cannel, at 18*s.* per ton—there will be a difference of £16,000 in the working capital required. The saving which can be made in this way, by producing 12-candle gas from any of the above cannels by the hydrocarbon process, is evidently of importance.

It cannot be overlooked, that a saving to London Companies in expense and trouble must result from the diminished quantity of coke which will have to be disposed of under the hydrocarbon process. Many of them know too well the difficulties and expenses arising in finding stowage-room and suitable markets. The cost of labour and office expenses consequent upon its sale is also an important item in their expenditure, and it must not be disguised that its value is likely to be considerably diminished ere long, owing to the arrangements making for the cheap transit of fuel-coals from the north.

The gases made under the hydrocarbon process are less liable to condensation and deposition of light-giving material, from low temperatures, than those made in the old way. For domestic use they are decidedly superior to any other, as they do not evolve so much heat, or generate so much carbonic acid gas during combustion, as the gases in general use. This circumstance alone would largely increase the consumption of gas in private houses.

SAMUEL CLEGG.

May, 1852.

The following results were arrived at by Dr. Frankland, Professor of Chemistry at Owen's College, Manchester. The experiments were conducted with scrupulous accuracy, their object being to obtain a fair comparison of the results yielded by the various coals when distilled alone (as in the usual process of gas-making) with those obtained from the same coals when treated with water-gas, according to the hydrocarbon process, previously described. Each coal was distilled, first by itself, and then with the addition of water-gas, equal weights being used for each experiment. The production of the water-gas was so regulated as to be most rapid at the commencement of the experiment, and then gradually to decline to its close. A rather low heat was employed, as it was found to be the best, as well for the coals alone as with water-gas.

The illuminating power was tested by Bunsen's Photometer, a large number of the experiments being made with an improved form of the instrument invented by Messrs. Church and Mann, of the City Gas-works, London. In some instances the shadow test was also tried. The size of burner and pressure of gas were in most cases noted, and in every instance the determination of illuminating power was made when the gas appeared to be burning to the greatest advantage—that is, without a flickering flame or a tendency to smoke. These experiments are however, even with the greatest care, subject to certain errors, caused principally by the irregular burning of the spermaceti candle, which renders them only approximative. The liability to these errors has, it is true, been much reduced by the ingenious plan of substituting a jet of gas for the candle, as proposed by Mr. King and Mr. Wright; yet the impossibility of accurately ascertaining the consumption of the candle at the moment when the gas-jet is made equal to it renders the experiments still liable to small inaccuracies. The following results are all corrected to those which would have been obtained by using a sperm candle burning 120 grs. per hour; and one of these candles, burning for 10 hours, is taken as the standard with which to compare the total quantity of light yielded by a given volume of gas; thus, when it is stated that the total quantity of gas produced from 1 cwt. of coal, when burned at the rate of 5 feet per hour, is equal in illuminating power to 546 candles, it is intended that the light afforded by the gas is equal to that yielded by 546 sperm candles, each burning 10 hours, and at the rate of 120 grs. per hour.

From Wigan Cannel (Ince Hall).

	Without Water-gas.	With Water-gas.
Cannel used	1 cwt.	1 cwt.
Gas produced	545 cubic feet	806 cubic feet.
Coke left	74 lbs.	68 lbs.
Time occupied	3 h. 20 min.	3 h. 20 min.
Illuminating power of the gas	5 feet per hour, equal to 22·1 candles.	5 feet per hour, equal to 20·0 candles.

	Per Ton.	Per Cent.
Hence gain in illuminating power by the employment of water-gas	1632 candles	33·9
Gain in quantity of gas	5220 cubic feet	47·9

Boghead Cannel.

	Without Water-gas.	With Water-gas.
Cannel used	112 lbs.	112 lbs.
Gas produced	662 cubic feet	1908 cubic feet.
Coke left	36 lbs.	37½ lbs.
Time occupied	2 h. 55 min.	3 hours.
Illuminating power of the gas	5 feet per hour, equal to 52·6 candles.	5 feet per hour equal to 50·6 candles.

	Per Ton.	Per Cent.
Hence gain in illuminating power by the employment of water-gas	10,028 candles	88·4
Gain in quantity of gas	24,920 cubic feet	188·2

In this experiment it was found impossible to generate more than one-half of the requisite quantity of water-gas from the water retort connected with that in which the cannel was distilled, and consequently another water retort had to be employed; but this, instead of pouring its gas into the coal retort, delivered it directly into the hydraulic main, thus reducing the advantageous operation of the water-gas in rapidly sweeping out the illuminating gases from the coal retort, and, in addition, preventing the removal of a considerable amount of carbonic acid, which materially diminished the illuminating power as indicated by the photometer. The experiment was repeated with a new apparatus, consisting of one coal and two water retorts, both of the latter delivering their gas into the lower division of the former: the other conditions were the same as before.

Second Experiment.

Cannel used	112 lbs.
Gas produced	2586 cubic feet.
Time occupied	3 h. 15 min.

The illuminating power of the gas burning at the rate of 5 feet per hour, from a Leslie's burner, is equal to 20 candles.

	Per Ton.	Per Cent.
Hence gain in illuminating power by application of water-gas	9348 candles	82·4
Gain in quantity of gas	28,480 cubic feet	290·6

LESMAHAGO CANNEL.

	Without Water-gas.	With Water-gas.
Cannel used	112 lbs.	112 lbs.
Gas produced	531 cubic feet	1459 cubic feet.
Coke left	54½ lbs.	49 lbs.
Time occupied	3 h. 20 min.	3 h. 18 min.
Illuminating power of the gas	4 feet per hour, equal to 28·7 candles.	4 feet per hour, equal to 19·1 candles.

	Per Ton.	Per Cent.
Gain in illuminating power by the application of water-gas	6,314 candles	82·8
Gain in quantity of gas produced	18,560 cubic feet	174·8

METHYL CANNEL.

	Without Water-gas.	With Water-gas.
Cannel used	112 lbs.	112 lbs.
Gas produced	478 cubic feet	1320 cubic feet.
Coke left	51 lbs.	51 lbs.
Time occupied	3 hours	3 hours.
Illuminating power of the gas	5 feet per hour, equal to 27·8 candles.	5 feet per hour, equal to 21·0 candles.

	Per Ton.	Per Cent.
Gain in illuminating power by application of water-gas	5,772 candles	108·6
Gain in quantity of gas	16,840 cubic feet	176·2

NEWCASTLE CANNEL (RAMSAY'S).

	Without Water-gas.	With Water-gas.
Cannel used	112 lbs.	112 lbs.
Gas produced	515 cubic feet	751 cubic feet.
Coke left	74½ lbs.	74 lbs.
Time occupied	3 h. 25 min.	3 h. 25 min.
Illuminating power of the gas	5 feet per hour, equal to 24·5 candles.	5 feet per hour, equal to 18·8 candles.

	Per Ton.	Per Cent.
Gain in illuminating power by application of water-gas	600 candles	11·2
Gain in quantity of gas	4720 cubic feet	45·8

Wigan Cannel (Balcarres).

	Without Water-gas.	With Water-gas.
Cannel used	112 lbs.	112 lbs.
Gas produced	522 cubic feet	775 cubic feet.
Coke left	68¼ lbs.	67¾ lbs.
Time occupied	3 h. 25 min.	3 h. 15 min.
Illuminating power of the gas	5 feet per hour, equal to 19·9 candles.	5 feet per hour, equal to 19·1 candles.

	Per Ton.	Per Cent.
Gain in illuminating power by employment of water-gas	1764 candles	42·4
Gain in quantity of gas	5060 cubic feet	58·5

A circumstance greatly in favour of the hydrocarbon gas is the less amount of carbonic acid generated during combustion than by the combustion of an equal volume of gas obtained from the same coals by the ordinary process of manufacture, as shown by the following table:—

NAME OF GAS.	Cubic feet of Carbonic Acid produced by combustion of 100 cubic feet of Gas.	Cubic feet of Carbonic Acid produced per hour by a light equal to 20 Candles.
Ince Hall Cannel	83·5	3·76
Ditto, with water-gas	69·5	3·47
Methyl Cannel	89·3	3·32
Ditto, with water-gas	71·5	3·40
Ramsay's Newcastle Cannel	90·9	3·64
Ditto, with water-gas	72·8	3·86
Lesmahago Cannel	113·9	2·95
Ditto, with water-gas	72·1	3·02
Boghead Cannel	127·2	2·96
Ditto, with water-gas	76·3	3·05

Summary of Experimental Results.

NAME OF COAL.	Cubic feet of Gas per ton.		Illuminating power per ton in Sperm Candles.		Gain per ton by White's process.		Gain per cent. by White's process.	
	By old process.	By White's process.	By old process.	By White's process.	Quantity of Gas in cubic ft.	Illumin. power in Sp. Cndls.	Quantity of Gas.	Illuminating power.
Wigan Cannel (Ince Hall)	10,900	16,120	4,816	6,448	5,220	1,632	47·9	33·9
Wigan Cannel (Balcarres)	10,440	15,500	4,156	5,920	5,060	1,764	48·5	42·4
Boghead Cannel	13,240	38,160	11,340	21,368	24,920	10,028	178·2	88·4
Ditto, second experiment	—	51,720	—	20,688	38,480	9,378	290·6	82·4
Lesmahago Cannel	10,620	29,180	7,620	13,934	18,560	6,314	174·8	82·8
Methyl Cannel	9,560	26,400	5,316	11,088	16,840	5,772	176·2	108·6
Newcastle Cannel (Ramsay)	10,300	15,020	5,046	5,646	4,720	600	45·8	11·2

Table, showing the quantity of Coal or Cannel requisite for producing light equal to 1000 *Sperm Candles, each burning* 10 *hours, at the rate of* 120 *grs. per hour.*

NAME OF COAL.	WEIGHT OF COAL.	
	By old process.	By White's process.
Wigan Cannel (Ince Hall) . .	465·1 lbs.	347·4 lbs.
Wigan Cannel (Balcarres) . .	539·0 „	378·4 „
Boghead Cannel	197·5 „	104·8 „
Lesmahago Cannel	293·9 „	160·7 „
Methyl Cannel.	421·4 „	202·0 „
Newcastle Cannel.	443·9 „	396·7 „
Newcastle Coal (Pelton) . .	745·7 „	—

In conclusion, the advantages resulting from the application of Mr. White's hydrocarbon process to coals and cannels may be thus summed up:—

1. It greatly increases the produce in gas from a given weight of coal or cannel, the increase being from 46 to 290 per cent., according to the nature of the material operated upon.

2. It greatly increases the total illuminating power afforded by a given weight of coal, the increase amounting to from 12 to 108 per cent., being greatest when coals affording highly illuminating gases are used.

3. It diminishes the quantity of tar formed, by converting a portion of it into gases possessing a considerable illuminating power.

4. It enables us profitably to reduce the illuminating power of the gases produced from such materials as Boghead and Lesmahago cannels, etc., so as to fit them for burning without smoke and loss of light.

5. In addition to these positive advantages, the use of this process does not incur any additional expense in the working of the apparatus, the wear and tear of retorts, or the purification of the gas; and, beyond a change of retorts, it involves no alterations in the construction of furnaces and apparatus at present employed in gas manufactories conducted on the old system.

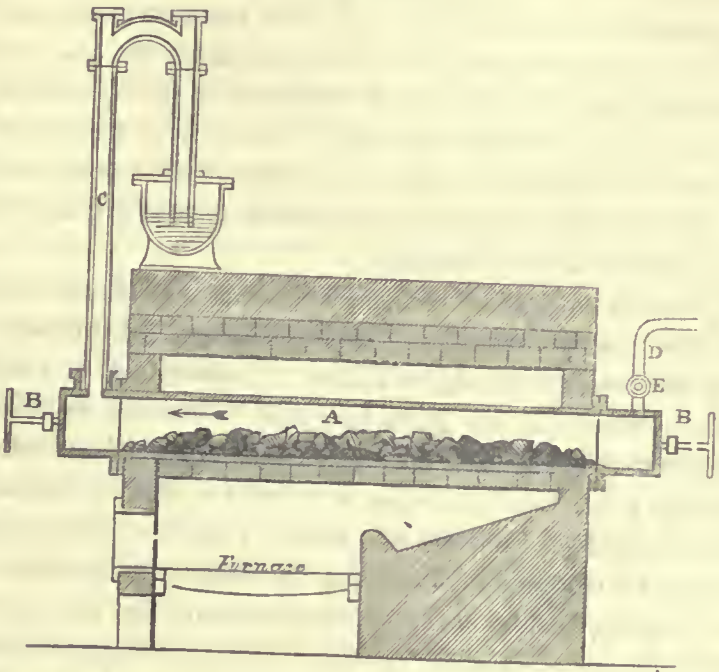
In January, 1852*, Messrs. Lowe and Evans patented a means of enriching or improving the quality of gases so as to render them fit for the purposes of illumination. In carrying out this improved manufacture of gas, the patentees pass gas obtained from wood, sawdust in a damp or dry state, spent tanners'-bark, and other substances capable of yielding an inflammable gas, through heated retorts containing cannel coal, coal, lignite, resin, pitch, tar, oil, retinite, or other

* See 'Newton's London Journal.'

substances capable of yielding carburetted hydrogen gas; by which means such a combination of rich and poor gases may be produced as will be exactly suited to the purposes of illumination.

For this purpose it is proposed to use retorts open at both ends, as shown in Fig. 20c, which represents a longitudinal vertical section of the apparatus employed.

Fig. 20c.



Only one retort is shown, but a similar arrangement of retorts may be adopted to that in general use in gas-works. A is the retort, set in a suitable furnace for heating it; and BB are mouth-pieces and lids fitted to both ends of the retorts; C is the pipe for carrying off the gaseous products generated in the retort; and D is a pipe for introducing into the retort the gas which is intended to combine with the gaseous products of the substances under distillation in the retort. As soon as the retort is charged with coal or other carbonaceous matter, a cock E, in the pipe D, is opened, which allows the gas to flow into the retort; and it then passes in the direction of the arrows, and mingles with the gas that is evolved from the carbonaceous matters contained in the retort, whereby a compound gas is formed, possessing a much higher illuminating power than could have been obtained had the combination taken place after instead of at the time of generation.

The gas which is brought to the retort by means of the pipe D may be forced into the retort, so as to overcome the internal pressure put on the retort by means of the hydraulic main; or an exhauster may be employed to draw off the gas from the retort. Should tar, oil, resin (previously melted), or any liquid hydrocarbon be employed for the generation of the gas, it is to be run into the retort in the way generally adopted for making oil or resin gas.

The substances, wood, etc., producing the non-luminous gases, must be put into red-hot retorts, and distilled like coal; the resulting gases may be either purified at once, or passed directly to the retort containing the coal. As a general rule however these gases are preferred to be stored in gas-holders for use, as in that case a more uniform and constant supply to the coal-retort may be relied on.

Another source of inflammable gas is from coal of an inferior description, or from peat: these substances having been distilled in a retort, the resulting gas can be then employed as above indicated.

It is also proposed to conduct carbonic oxide gas into retorts containing carbonaceous matters under distillation. This gas the patentees obtain by passing carbonic acid gas through a retort or furnace containing red- or white-hot coke; or they utilize a portion of the gases generated in furnaces by collecting these gases, and converting the carbonic acid they contain into carbonic oxide by passing them through a retort or furnace, as described for treating carbonic acid; or the gases may be conducted directly into retorts, wherein carburetted hydrogen is being generated, for the purpose of effecting the desired combination.

From the foregoing description, it will be understood that the object of the invention is to obtain gas of a uniform quality—that is, possessing a definite amount of illuminating power. Now it is well known that if the gas be too rich in carbon it will burn with a dull flame, and give off a large amount of smoke; and that if deficient in carbon it will burn with a blue flame, and possess very little illuminating power. It is therefore proposed to mix the rich and poor gases, obtained as above described, in such proportions as will be needful to produce a highly illuminating quality of gas. As the proportions will depend entirely on the quality of the gases to be combined, no rule can be laid down for the amount of the gases required to be passed into the retorts wherein the distillation is proceeding. The mode however in which the gas burns on issuing from the retort will be a sufficient test for the workmen in attendance.

BRICKWORK*.

In Plate IX. are represented sections and a plan of a retort-house, to a scale of a quarter of an inch to the foot, containing thirty benches of retorts, capable of producing 300,000 cubic feet of gas in twenty-four hours from Newcastle coal.

The interior dimensions are—length, 116 feet 7 inches—width, 44 feet 8 inches—height from the ground-line to the firing-floor, 8 feet $5\frac{1}{2}$ inches, and from thence to the wall-plate 14 feet, making the total height 22 feet $5\frac{1}{2}$ inches. The thickness of the outer basement walls is 18 inches, and from the firing-floor to the roof 14 inches. They are well tied together and supported throughout.

In the basement, semicircular arched openings of five feet three inches' span run the entire length of the building, except the two at the ends, which are filled in, to give additional strength to the angles. By means of these openings a free current of air is allowed entirely through the coke-cellar; and if the coke be well spread abroad immediately it is drawn from the retorts, no inconvenient heat is suffered.

The space occupied by the arches in which the retort-benches are built is 102 feet 10 inches long by 15 feet 11 inches broad, with one arch of 5 feet 3 inches' span at each end†.

The piers are 18 inches thick by 15 feet 11 inches wide, built from nine-inch inverts, and carried up 3 feet 3 inches, at which height the semicircular arches spring. The spandrils of these are faced with nine-inch work, and the centre space filled in with concrete or brick rubbish.

Plumb with the centre of each pier, level with the crown of the arches, and having a bearing, at one end upon the face of the spandril, and at the other in the

* See Appendix.

† When worked out, these dimensions most probably will be exceeded; but I never lose an opportunity, in cases like the present, of giving the workmen odd inches in their dimensions: they may not always work to them, but it increases the probability of correctness.

outer wall, are placed the cast-iron girders G G, from which the flat segments spring that support the flags of the firing-floor. The rise of these arches is about twelve inches, formed of well-burned cut stocks, and carried from the outer wall of the house to within two feet of the face of the retort-benches. These flat arches are likewise carried across the coal-stores and supported in a similar manner, as represented in the cross section. The backings are filled in with concrete.

The ovens for the reception of the retorts are separated by a 14-inch wall running the entire length of the beds. In the immediate vicinity of the furnace it must be constructed with fire-bricks laid English bond.

The walls on each side of the furnaces must be of Stourbridge fire-bricks, and nine inches thick, as high as the springing of the arch, which is $4\frac{1}{2}$ inches thick, turned with moulded bricks of the same description. The space between the furnace-walls is fourteen inches. All the solid parts may be filled in with brick rubbish.

In turning the arches of the ovens, great care must be taken that the joints are closed, and for that purpose the clay used for setting the bricks must be rendered fine with continued working. The bricks must be the best Newcastle, moulded to fit the curve. The flues must be faced with nine-inch work, the intermediate spaces between the ovens filled in with concrete or brick rubbish.

H H is the hydraulic main.

P P is the position for the cast-iron columns which support the main.

Q is the pipe which conveys the gas to the separators or condensing pipes SS, and should run back the entire length of the retort-house before joining them, in order that the crude gas may be kept in prolonged contact with the tar condensing from it.

The roof is of wrought-iron, constructed in the form shown in the engraving: the principals are twenty-two in number, eleven on each side, supported in the centre of the house by cast-iron pillars resting on the wall which separates the retort-ovens. The dimensions of the iron-work are,—the principal rafters are Ts three inches by five-eighths of an inch; tie and brace-rods $1\frac{1}{4}$ inch round iron. The ventilator on each division is also of wrought-iron, with the exception of the louvre-boards, which are of three-quarter yellow deal or pine. The covering of the roof is of Countess slate.

In the design for a retort-house many things must be taken into consideration. The principal circumstances that will guide the builder in the construction, irrespective of the dimensions necessary for the required number of benches, are, first,

the nature of the soil, upon which will depend the depth of the foundations, the spread of the footings, etc.: in made earth and marshy ground it is necessary to build upon piles, or upon a bed of concrete, composed of river ballast, or gravel, free from argillaceous matter, and ground lime mixed intimately together with water, and thrown into the excavation from a height of some feet. Secondly, the builder must consider the extent of the funds upon which he has to draw. This, of course, is an important point, and it is a merit if he gives the "*most for the money*" without exceeding the estimate: upon this latter consideration will depend the arrangement of the ovens, coke-cellar, and coal-stores.

The cost of a retort-house, of the dimensions before given from the ground-line, will be as follows:—

	£.	s.	d.
Outside walls and centre portion as high as the firing-floor, including cast-iron girders, York landings for firing-floor, coal-stores, etc.	1975	0	0
Wrought-iron roof	320	0	0
Brickwork for ovens, including the setting of 150 retorts, etc.	600	0	0
Chimney, 120 feet high	180	0	0
	£3075	0	0

The capacity of a coal-store should be accurately ascertained, and made fully equal to hold six weeks' consumption of coal in the winter season, especially in those situations where it is carried by water; because, during severe frosts, canals are often rendered impassable for that period. I do not refer to the neighbourhoods where coal abounds—where sometimes the pit-mouth is not a mile from the works—but to those districts where coal is valuable, and difficult to be obtained except through the regular channels*.

A ton of coal, economic weight, will occupy from 40 to 48 cubic feet, the space depending upon the specific gravity of the coal and the size of the lumps; therefore in an establishment such as that at page 174, which produces 117,000 cubic feet of gas in twenty-four hours, the stores should be capable of holding 600 tons of coal, or have a cubical content of 26,400 feet between the entrances. This however is seldom if ever attended to; stores are generally made to contain about

* Coal is in many instances conveyed as cheaply by railway as by canal, and as the delivery is very certain, works near a line, especially if they have a "siding," need not provide for any large stock.

two weeks' consumption, the excess being stacked outside the house and covered with tarpaulins, which quantity should be used first.

In the example just referred to the spaces were divided into three, by passages five feet wide, the entire length of the store being seventy feet; the spaces for the coal were fifteen feet by twelve at each end, and one thirty feet by twelve in the centre: 200 tons could be stored with convenience. When full, the stacks must be retained by three-inch planks, placed vertically and strutted, spaces being left to work the coal.

As a check upon the delivery and use of the coal, the walls of the stores should be marked at certain heights corresponding to five or ten tons; and every charge of coal should be weighed, either by a meter, with an index to register the quantity used at stated periods, or by a simple weighing-machine, the fireman tallying his charges.

The adjoining cut (Fig. 21) represents a retort-house built of brick, upon the most simple construction, and well adapted for a town requiring 80,000 cubic feet of gas for the supply of the longest night in the winter season, or 14,800,000 per year. Being without coke-cellar, the charges must be drawn into wrought-iron barrows, the contents wheeled into the open air, and spread abroad to cool*.

The outside walls are calculated to give the necessary security with the least possible material. The piers *a a* are eighteen inches thick at the base, projecting $4\frac{1}{2}$ inches (on the outside) from the brickwork filling the space between them. Half-way up the walls there is a $4\frac{1}{2}$-inch offset, which leaves the thickness of the panels fourteen inches below, and nine inches above the offset.

The roof is of wrought-iron, covered with common pantiles. The ventilator is of wood.

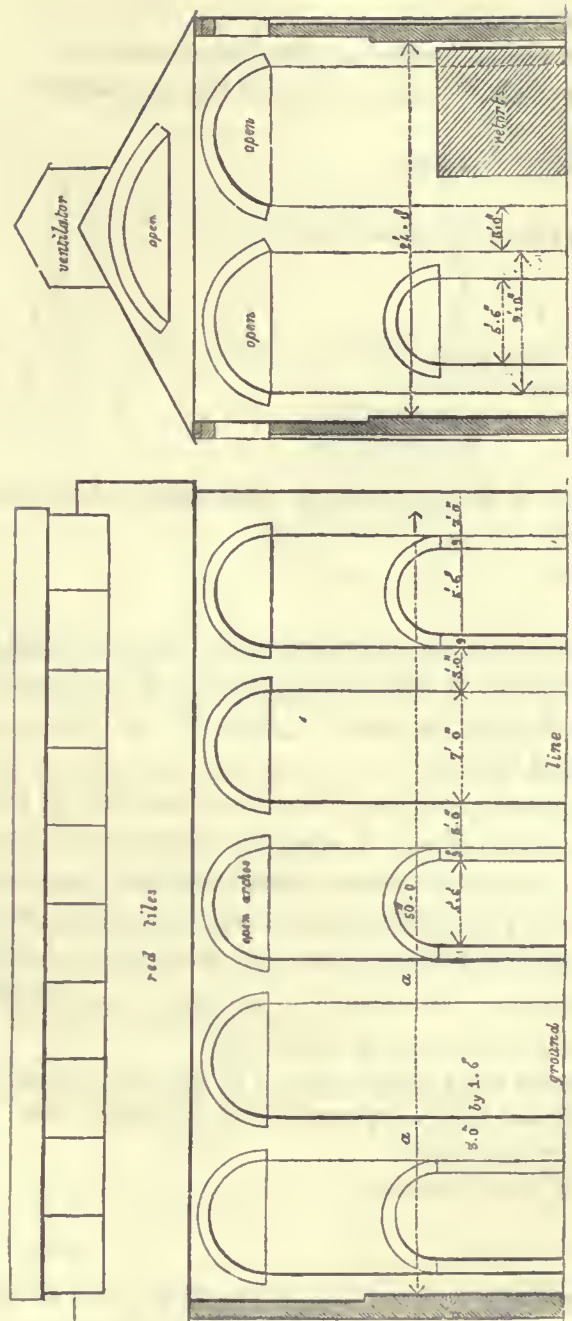
The estimate for this house, including a chimney seventy feet high from the ground-line, was £550. The cost of the ovens for the reception of the retorts, eight in number, was £57, and the setting of the retorts cost £103.

The retorts were set five in one oven, making forty retorts, which will allow two extra benches for repairs.

In twenty-four hours thirty working retorts will carbonize 240 bushels, or 180 cwt. of coals, and produce about 82,000 cubic feet of gas from Newcastle coal.

* The furnaces should be fed with this hot coke.

Fig. 21.


ventilator
open
open
open
retorts
red tiles
open arches
ground
line

The following may be taken as the average cost of producing 1000 cubic feet of gas by such sized works :—

Dr.			*s.*	*d.*
To coals, 18*s.* per ton (producing 9200 cubic feet per ton)			1	11·45
„ fuel (30 per cent. of coke produced, @ 15*s.* per chaldron)			0	5·85
„ labour			0	4·75
„ wear and tear of retorts			0	3·25
„ lime			0	0·50
„ wear and tear of works and mains			0	3·50
			3	5·30
Cr.	*s.*	*d.*		
By coke sold, @ 15*s.* per chaldron	0	9·77		
„ breeze, tar, etc.	0	1·00		
			0	10·77
			2	6·53
To this must be added the cost of distribution and the loss by leakage, say			0	6·00
			3	0·53

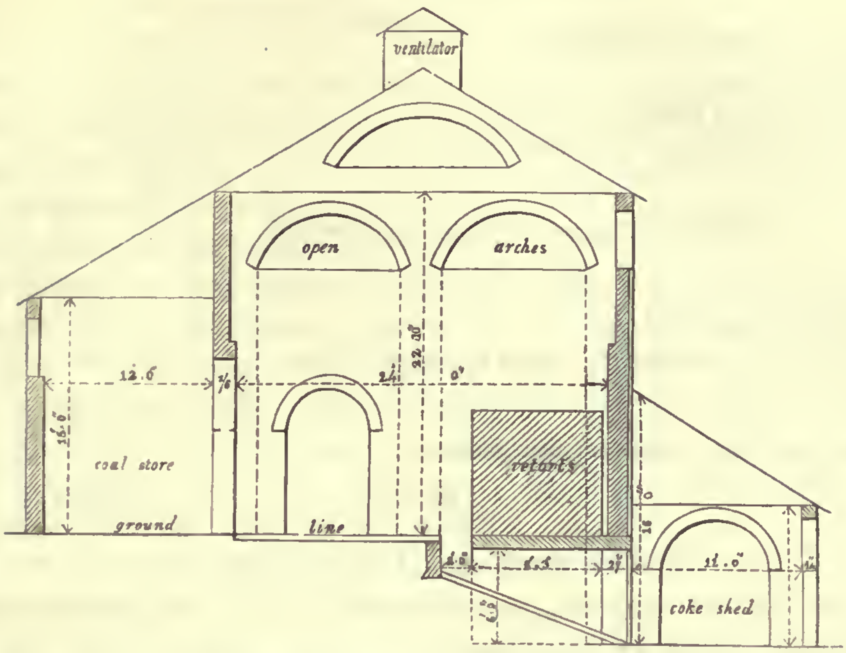
In this example (Fig. 22) advantage was taken of sloping ground to form a coke-shed, which saved a considerable quantity of brickwork. The charge, as it was drawn, fell through the space in front of the retorts, and down an inclined plane into the shed behind.

This house is considerably larger than that described in the last example, being capable of making 21 millions of cubic feet annually, and is furnished with a coal-store. It may perhaps be as well to state here, that coal from which gas has to be distilled should, if possible, be always kept under cover, because, when moisture is present, the hydrogen arising from the decomposition of water will deteriorate the quality of the gas. It is therefore a matter of economy to construct a sufficient shed to preserve the coal in a dry state.

	£.	*s.*	*d.*
The contract for this building, which is 70 feet long, including a chimney 90 feet high, independent of the foundations, was	1200	0	0
A wrought-iron roof, slated	190	0	0
Ventilator, of wood, and slated	43	0	0
	£1433	0	0

Eleven benches of retorts set complete = £220 ; cost of retorts = £268. 2*s.* 6*d.* The house contained fifty-five retorts, allowing two benches of five retorts each

Fig. 22.



for repairs. The coal carbonized by the remaining forty-five retorts was 360 bushels, or 270 cwt. in twenty-four hours, producing 120,000 cubic feet of gas, being 9000 to 1 ton.

The following is the average cost of producing 1000 cubic feet of gas at these works:—

Dr.			*s.*	*d.*
To coals, 19*s.* 6*d.* per ton (producing 9000 cubic feet per ton) .			2	2·00
„ fuel (30 per cent. of coke produced, @ 16*s.* per chaldron) . .			0	7·57
„ labour (including foreman, who acted also as collector and clerk, @ £78 per annum)			0	4·10
„ wear and tear of retorts (average of nine years)			0	3·17
„ lime			0	0·61
„ wear and tear of works and mains (average of nine years) . .			0	3·29
Total			3	8·74
Cr.	*s.*	*d.*		
By coke sold (1380 chaldrons, @ 16*s.*)	1	0·61		
„ tar, @ $1\frac{1}{2}$*d.* per gallon	0	1·36		
„ manure, lime, old iron, etc.	0	0·03		
			1	2·00
			2	6·74

Cost of Distribution per 1000 *cubic feet.*

	s.	d.	s.	d.
Repairs in streets, and new mains	0	2·47		
Rates and taxes	0	1·02		
Stationery and incidental expenses	0	0·68		
Labour and repairs of 203 street-lamps	0	1·85		
			0	6·02
Total (including 2*s*. 6·74*d*. brought forward)			3	0·76

	£.	s.	d.
By 203 lamps, @ £4. 4*s*.	852	12	0
By gas sold by consumers' meter, 14,375,000 @ 6*s*.	4,312	10	0
	5,165	2	0
Less cost of production and distributing	3,082	10	0
Profit	£2,082	12	0

Being $9\frac{1}{8}$ per cent. upon a capital of £22,727.*

A retort-house, 200 feet long and 54 feet wide (in other respects the same as that exhibited at Plate IX.), will cost—

	£.	s.	d.
Brickwork in outside walls, iron girders, flagged firing-floor, and centre portion for supporting retort-benches	3950	0	0
Wrought-iron roof, slated	700	0	0
Chimney, 120 feet high	180	0	0
	£4830	0	0
250 retorts set in a similar manner to those shown in Plates I. and II., including hydraulic main, dip-pipes, brickwork, complete	5000	0	0
Total cost of retort-house when furnished	£9830	0	0

The cost of building depends upon the price of bricks, lime, labour, etc., and will vary in different localities.

* For cost of production and distribution for large works, see Appendix.

CONSTRUCTION OF CHIMNEYS.

Previous to entering upon the particulars of the construction of gas-works chimneys, I would remark, that it may afterwards be found convenient, from an increase in the number of retorts, to have a chimney built considerably larger than is necessary for the actual number for which it is erected, as the expense bears a small ratio to the increase of size.

The draught absolutely required for the proper combustion of the fuel beneath the retorts is little; indeed, that usually given to a common coke-oven would be sufficient*. It is necessary to build a high chimney however to carry off the smoke, which, if not allowed to spread, would become a nuisance to the neighbourhood†. But whatever the height, the shaft-flue must be of equal area from bottom to top. The height of a chimney does not decrease the *quantity* of smoke, but distributes it over a larger surface, and causes less inconvenience.

To obviate any excess of draught, it is advisable to make a valved opening into the bottom of the shaft communicating with the external air. The dampers of the retort-flues might be used to adjust the draught; but this would be relying too much upon the workmen. It often happens, if there is no check, that during the night the heat of the ovens will be neglected, and suffered to fall below the proper temperature; and then, to make up, the dampers are opened and the furnaces forced, to the deterioration of the retorts, the waste of fuel, and the production of inferior gas. When there is an air-opening into the shaft this cannot be done, and there will therefore be less danger from such carelessness.

With this precaution, the chimney may with advantage be built seventy feet high even for a small number of retorts; but the height of the shaft must always be regulated by the description of property surrounding or in the vicinity of the works.

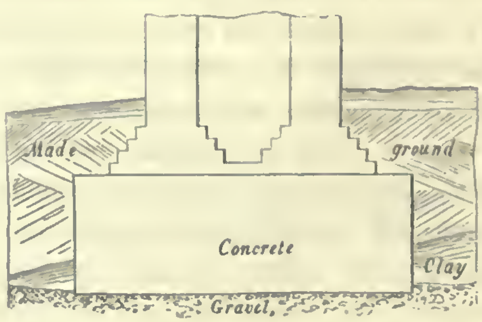
The foundation of a structure bearing a great weight upon a small surface must be carefully attended to. If a good natural bottom is not to be obtained, an artificial foundation must be made, either by concreting or driving piles; the former is generally sufficient. At the spot upon which the structure is to be raised, the different strata immediately beneath the surface must be examined by boring,

* For the principles on which the power of draught must be calculated, see 'Encyclopædia Britannica,' last edition, article "Furnace," by Mr. George Buchanan, F.R.S.E.

† The chimney-shaft built for the Edinburgh Gas-works is 330 feet high; that for the chemical works at Glasgow is 420.

until some definite stratum be reached: by a reference to the depth of this bed, some idea of the extent of excavation is arrived at. In all cases the foundation must be equally resistant, that is, all parts of it must be capable of bearing the same amount of pressure; if this is not attended to, unequal settlement is sure to result. In all cases the "made earth" must be removed. If the stratum immediately beneath is of clay*, gravel, chalk, or other firm bed, and found to be sufficiently thick for a solid bearing, the excavation may be finished and the foundation laid in. In the neighbourhood of London the substratum is generally made earth, beneath which, at variable depths, not often exceeding twelve feet, a good bottom is usually met with, when, to save brickwork, concrete may be thrown in, until only enough depth is left from the surface to cover the footings of the chimney, as shown in Fig. 23.

Fig. 23.



I cannot give a better example of the value of concrete than by referring to a chimney that was built by Mr. Clegg at Fulham, in 1829. The foundation was a quicksand. After the excavation was got out to the depth of fifteen feet, an iron rod sank, with little more than its own weight, fifteen feet more; it was, in fact, as bad a foundation as could possibly occur. In Plate X. I have given a representation of this chimney, which will explain the construction. During its erection it settled bodily down 16½ inches, without a crack, or deviating in the least from the plumb. It therefore follows, that the only disadvantage attending a bad natural foundation is the expense of making an artificial one. It perhaps will not be out of place to insert here the following extract from Mr. Farey's Treatise on the Steam-Engine, which relates to the erection of an extensive building upon bad ground.

* Clay must not be built upon at a less distance from the surface than six feet.

"The building for the Albion Mills was erected upon a very soft soil, consisting of the 'made ground,' at the abutment of Blackfriars Bridge: to avoid the danger of settlement in the walls, or the necessity of going to a very unusual depth with the foundations, Mr. Rennie adopted the plan of forming inverted arches upon the ground over the whole space upon which the building was to stand, and for the bottom of the dock. For this purpose the ground upon which all the several walls were to be erected was rendered as solid as is usual for building by driving piles where necessary, and then several courses of large flat stones were laid to form the foundations of the several walls; but to prevent any chance of these foundations being pressed down in case of the soft earth yielding to the incumbent weight, strong inverted arches were built upon the ground between the foundation courses of all the walls, so as to cover the whole surface included between the walls; and the abutments or springings of the inverted arches being built solid into the lower courses of the foundations, they could not sink unless all the ground beneath the arches had yielded to compression, as well as the ground immediately beneath the foundation of the walls. By this method the foundations of all the walls were joined together so as to form one immense base, which would have been very capable of bearing the required weight, even if the ground had been of the consistency of mud; for the whole building would have floated upon it as a ship floats in water; and whatever sinking might have taken place, would have affected the whole building equally, so as to have avoided any partial depressions or derangement of the walls; but the ground being made tolerably hard, in addition to this expedient of augmenting the bases by inverted arches, the building stood quite firm."

When the foundation has been properly disposed of, the brickwork may be commenced. The bricks should be well burned, and sound stocks set with a thin joint. The proportions for the mortar will be regulated by the quality of the lime, but, as general rules, one part of grey-stone lime, such as Dorking, to three parts of clean sharp river-sand, or one part of lias lime and two parts of sand, are good proportions; mortar made with white-chalk lime is worthless. At the distance of about every fifteen feet, a wrought-iron hoop, two and a half inches deep and half an inch thick, must be built into the brickwork as the chimney rises; this is necessary to avoid cracks. The interior of the flue must be parged with fire-clay and chopped straw, laid on as plaster.

The cost of a chimney will depend upon the foundation and the extent of finish and ornament given to the shaft. A well-proportioned circular shaft is ornamented *per se;* a bold base moulding and cap are the only embellishments required. The cost of the foundation to the Fulham chimney was as follows:—

	£.	s.	d.
287 cubic yards of excavation and retaining, at 1*s*. 6*d*. . .	21	10	6
143¼ cubic yards of concrete, at 7*s*. 6*d*.	53	16	3
400 super feet of Yorkshire flagging, six inches thick, at 2*s*. 1*d*. .	41	13	4
26½ cubic yards of brickwork in mortar, at 21*s*.	27	16	6
287 cubic yards of filling-in, ramming, and spreading, at 3*d*. .	3	11	9
	£148	8	4

The contract for the remaining part of the chimney above the ground-line was taken at £117. The situation for the chimney of a retort-house may be at the end, at the side, or removed to some distance from the building*; the first position is the most convenient. If the house is of considerable extent, it is usual to erect the chimney in the centre, dividing the retort-benches into four sections.

FIRE-BRICKS, ETC.

The parts of the furnaces exposed to heat are built of bricks made of a description of clay free from alkaline earths and iron, which is to different extents infusible, the qualities chosen for use being regulated by the degree of heat to which they are to be exposed. They are known in commerce by the names of Bristol, Stourbridge, Newcastle, Welsh, and Windsor bricks. The first of these are composed almost entirely of silex, and are infusible at the greatest heat of the blast-furnace; but they are very costly, and seldom used. The second quality are made from clay found in the neighbourhood of Stourbridge†, lying in a stratum of

* At Dolphinholme, in Lancashire, where a large worsted-mill was lighted with gas, it was requisite to remove the chimney to some distance, the dwelling-house of the owner being close by. For this purpose the flue was carried along a field, rising about 1 in 20, for a quarter of a mile, and on the summit of this rise the chimney was erected, in the form of an obelisk.

† The celebrated Stourbridge clay lies about 15 feet beneath the lowest of three workable seams of coal (each averaging 6 feet thick), worked at Stourbridge in the lower coal-measures in the south-western extremity of the Dudley coal-field. The bed of clay is 4 feet thick, and the following is the composition, according to Berthier, quoted in Dufresnoy's 'Mineralogie,' vol. iii. p. 259:—

Silica	63·70
Alumina	22·70
Oxide of iron	2·00
Water	10·30
	100·00

considerable thickness in the lower coal-measures; they are used in the construction of furnaces required to resist great heat, such as those for smelting iron-ores, glass-making, etc., and sometimes for the linings of retort-ovens: for this latter purpose I consider them too expensive, except for the arch immediately over the furnace, as the heat is not intense. The third variety are composed of the clay lying above the coal-measures in Northumberland, and for the construction of retort-furnaces and ovens are the most desirable. All parts of the ovens may be built of Newcastle brick, except the arch above-mentioned. Welsh bricks were until lately used for the parts less exposed to heat, because they were the cheapest; now however Newcastle bricks are less by 10*s.* per thousand. Welsh bricks are liable to "honeycomb" when heated, owing to the admixture of inferior clay and extraneous matter. The Windsor bricks, made at the village of Hedgesley, are good, and bear the same price as Newcastle. Fire-lumps are made in various shapes and of different sizes, and may be obtained to suit any purpose of oven-work if ordered; those kept on stock vary from 4 to 6 inches thick, and from 12 to 36 inches long. Fire-tiles are made from $1\frac{1}{2}$ to 3 inches thick, and from 9 to 24 inches long: their application has already been explained.

In setting these bricks, etc., care must be taken to use the same clay as that of which the brick is composed, and to have the joint close; for this purpose the clay must be well "tempered" with little water, and the brick or lump well bedded; if the lump is of large dimensions, a "maul" should be used. The work must be suffered to dry before heat is applied, and even then by slow degrees.

The following is an extract from Mr. G. Lowe's report to the Jury of the Exhibition of 1851:—

"One especial feature in Mr. Cowen's bricks and retorts visible to the eye, and so essential to their withstanding high heats, is their freedom from iron, which acts the part of a flux, destroying the otherwise many good properties of fire-clays. This he arrives at by the following Chinese practice of submitting his clays exposed for years to all weathers, turning it frequently over, whilst young hands pick out the fossiliferous fragments, generally pyritous, which this disintegrating process lays open to observation. The clay contains a high percentage of silica. Add to these points great care in the manufacture, in which every appliance is to be seen, and we have nearly the secret of Mr. Cowen's fame. He has testimonials from all quarters; one from Rouen, dating thirty-eight months as the durability of some of his retorts, being four times that of iron ones.

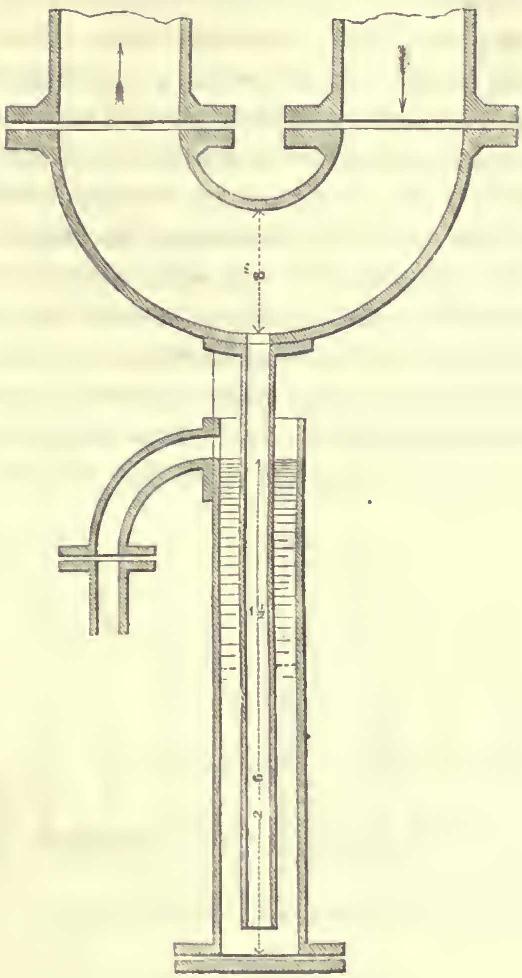
"The fire-bricks exhibited by Messrs. Cowen are sold at from 40*s.* to 50*s.* per 1000 on board at Newcastle, the price varying with the size; the same articles are delivered in London at from 50*s.* to 70*s.* The retorts are from 60*s.* to 80*s.* each at Newcastle, and in London from 5*s.* to 10*s.* more."

CONDENSERS.

The gas, when it leaves the retorts, retains its impurities, and in this state is quite unfit for internal illumination, or even for public thoroughfares. The impurities are chiefly bituminous vapour, essential oil, ammoniacal gas, sulphuretted hydrogen, carbonic acid, naphthalin, and bisulphuret of carbon; the processes adopted for removing these are partly mechanical and partly chemical. The first operation is the condensation of the volatile portions, which is effected at different places in different ways. The condensers adopted either consist of a series of pipes arranged in the manner of a distiller's worm, or of a number of chambers contained in a tank and surrounded by cold water; at the lowest points of these vessels siphons are attached, sealed by dipping them into tar to a sufficient depth to prevent the gas from escaping, and through them the condensed bituminous and ammoniacal vapours pass away to the cistern constructed to receive them in the forms of tar and ammoniacal liquor.

The same tank serves to contain both, the difference of the specific gravities keeping them separate; the ammoniacal liquor, being the lightest, swims on the surface of the tar. The tank is generally sunk below the surface of the ground; the respective heights of the two fluids are registered by floats and gauges, and when found necessary, are pumped out. If there be no sale for the tar, it is burned beneath the retorts; and the ammoniacal liquor is either evaporated in the cast-iron pans placed under the furnaces for that purpose, manufactured into the carbonate and muriate of ammonia, or used as manure. The simplest and best condenser is formed of upright pipes, as shown in Plate IX. at S S; their number and length being regulated by the quantity of gas required to pass through them; in height they may be equal to that of the wall of the retort-house, for the convenience of placing a tank on the roof to supply them with water; but an increase in height is always attended with increased efficacy. In this instance the tank was placed against the chimney, thus allowing a greater *length* of pipe; at the bottom of each bend is a siphon, similar to that represented in the annexed woodcut, by which the condensed vapours before mentioned are conveyed to separate vessels, the fluids passing away being of different values (that from the last siphon is the most valuable).

Fig. 24.

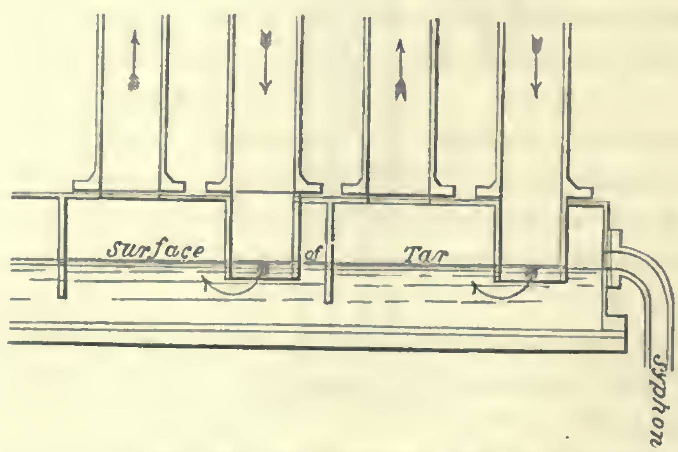


These pipes may be kept wet, in warm and dry weather, by small streams of water running on to them, from a tank placed at the top of the retort-house. The quick evaporation of this moisture will keep the pipes much colder than if they were completely immersed in water; because, as a large quantity of caloric passes from a sensible to an insensible state during the formation of vapour, it follows that cold should be generated by evaporation. If the sun shines upon the pipes, they will be colder than when it does not (always supposing the quantity of water supplied is greater than the evaporation), owing simply to the quicker generation of vapour.

The most volatile of the impurities contained in crude gas is naphthaline, and cannot be entirely separated by mere cold; its flaky crystals being often found in the street-mains at great distances from the works. The inconveniences and trouble caused by this deposit are well known by all managers of gas-works; its complete removal therefore must be carefully provided for.

Coal naphtha has a great affinity for it, and the most simple mode of keeping it in contact with this oil, is to prolong the pipe from the hydraulic main as much as possible before it joins the vertical condensers; the larger the diameter of the pipe the greater should this length be, and, as an approximate rule, ten feet run for every inch of the pipe's diameter will not be found far wrong, the working pressure being two inches. Increased pressure will of course require increased length in the ratio of their square roots; thus a pressure of four inches will require the length to be 14′ 6″ instead of ten feet. As a further precaution, a tar box might be added, into which the open end of the pipe might dip, as shown in 24[a].

Fig. 24a.

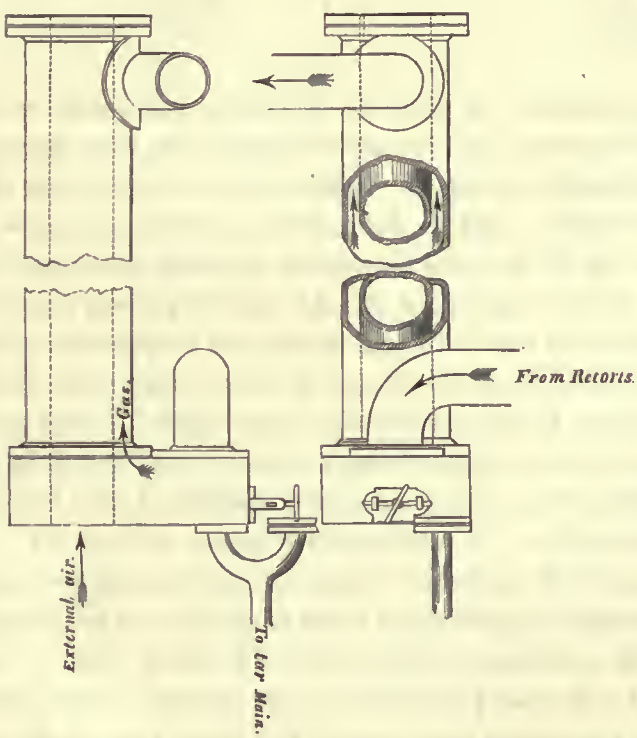


This figure represents an arrangement for the bottom of the condenser pipes, which is preferable to that shown in Fig. 24, because of the difficulty of getting at the siphons to cleanse them, and other practical objections probably well understood by my readers. Every part of a condenser, at all liable to be choked, must be provided with the means of being cleansed. As a further precaution against the naphthaline nuisance, the "scrubbers" may be supplied with coal-naphtha, to be mentioned further on.

In the arrangement of the condensers or separators, as much *surface* as possible

should be provided. In simple pipes, especially when of large diameter, the central portion of the gas passing through them is not brought into contact with the exterior, remains therefore uninfluenced by cold, and passes, in a great degree, uncondensed to the purifiers. An internal pipe, open to the atmosphere at each end, forming with the external one an annular space for the gas to pass through, makes an unexceptionable condenser, and greatly increases the cooling surface. Thus, suppose a 12-inch pipe to be the diameter required for the passage of the gas to the condensers, the surface would be 480 square inches per foot run; but the annular disposition would present a surface of 1216 square inches, the space being equal in area to the 12-inch pipe, viz. 113 inches. The upper and lower ends of these condenser-pipes may be joined to their neighbours, and to the tar-receiver by single pipes, as shown in Fig. 24^b. There are several ways in which the junctions can be effected, but it is not necessary to describe them.

Fig. 24^b.



The different states in which the crude gas is presented makes it impossible to give a certain rule for the determination of the area of the exposed surface: it is

perhaps dangerous to venture upon even a general one; but I may say that, from experience, I have found a surface of 150 feet for every 1000 cubic feet per hour to be about sufficient, when the stratum of gas has not exceeded three inches in thickness, and this without the application of a water-shower. The temperature of the external atmosphere will necessarily exert a very considerable influence upon the action of the condensers. In summer the surfaces of the pipes may be almost as hot as the crude gas entering them: in winter they may be at 32°; and there is little doubt that all descriptions of coal-gas experience some loss of illuminating principles on exposure to this degree of cold, the richest gases losing the largest amount, as shown by the following table:—

NAME OF GAS.	Cubic feet of Hydrocarbons condensed from 1000 cubic feet of Gas on exposure to a cold of 32° Fahr.
Boghead	4·42 cubic feet.
Ince Hall	0·37 „
Methyl	0·33 „

A uniform temperature of about 50° should be maintained as nearly as practicable; and a water-tank, in extremes of temperature, from whence water might trickle, is the simplest means of regulation, as in hot weather the evaporation would be very effective, and in sharp frosts a steam-pipe might be introduced into the tank. At the Imperial Gas-works moveable covers are placed over the internal pipes, which when closed in cold weather prevent a current of air passing through them, and permit the gas to raise the temperature of their surfaces.

Managers of gas-works would do well to attend more to the condensation than they do at present. If after condensation "dry lime*" is used for purifying, the gas is passed by some engineers through a wash-vessel; but it is a custom fallen much into disuse, and would not have been mentioned here had it not been noticed in the first edition. A wash-vessel is shown in Plate XI. A is the inlet-pipe for the gas, which displaces a column of water about three inches high, and passes first through the openings *b b b* and at the sides of the wrought-iron box B, then through the continuous opening or slit C C (which must be equal in area to that of the inlet and outlet pipes,—viz. in this example, 50·265 square inches, the diameter of the pipes being eight inches), and finally through the water. The use

* The term "dry lime" is used in contradistinction to lime-water, the first being simply a hydrate, the latter holding lime in suspension with a large quantity of fluid.

of the opening C C is to divide the gas into small portions, and distribute it over a large surface. The more minutely it is divided, the better will the wash-vessel effect its object.

D is the outlet-pipe*.

E is a siphon, for maintaining the water at a certain level; the part which enters the tank is conducted to the bottom, in order that the sediment may run off. The upper end of this dip-pipe is open, or it would otherwise form an actual *siphon*, and drain the tank.

F is a portion of a condenser, called by workmen a "gridiron condenser," which, when separators are used, may be dispensed with.

* A better situation for the outlet-pipe is represented by the dotted lines on the top of the vessel, since all liability of its filling with water is avoided.

PURIFIERS.

The condensed gas has now to be purified to as great an extent as possible from sulphuretted hydrogen, carbonic acid, ammonia, and the fatty oils still present. The first of these, sulphuretted hydrogen, is the chief impurity, and at the same time the easiest to remove: hydrate of lime was the first substance employed by Mr. Clegg for this purpose, and practice has not substituted a better. Various salts have been suggested, and some of them tried; but it would appear that a return to the use of lime has been universal. If a medium were discovered for the removal of the ammonia and bisulphuret of carbon, as well as the sulphuretted hydrogen, that would be at once efficacious, cheap, and free from objections arising from complicated manipulation, it would doubtless be a great boon to the gas-manufacturer; but in the absence of such a one, lime is alone left to us; and since purification by its means costs but one halfpenny per thousand cubic feet on the average, we need not regret the alternative on the score of economy.

The best lime we can procure in England for our purposes is that made from chalk, it being the purest native carbonate. The oolitic, the magnesian, and lias lime-stones are inferior exactly in proportion to the amount of earthy or foreign matter they contain. A comparison of limes is very easily made by dissolving them in diluted acid: that which leaves the least insoluble base or sediment is the best.

There are two kinds of machines for purifying by lime,—one arranged for "dry lime," the other for lime-water. The first is considered the most effectual, convenient, and economical, because the purifying agent can be brought into close contact with the gas without loss of lime, because the machine works without pressure, and because the spent lime, or matter left from the process, is less of a nuisance. In some establishments both kinds of machines are used.

In preparing the lime for the dry purifiers, it should be beaten, sifted fine, and water added, until, by compression in the hand, it will retain the form thus given to it; if any lumps remain, their outsides alone are acted upon, and the interior remains pure, thereby causing a waste of lime.

The quantity of lime required to effect the purification of a certain quantity of

coal-gas depends upon the quality of both; one bushel of quick-lime, reduced to a hydrate, may be taken as the average quantity required to purify 10,000 cubic feet of gas, but the manager must make his own experiments as to the absolute quantity required in his particular case. One bushel of quick-lime, when slaked and reduced to the proper consistency for use, will have its bulk doubled, and this quantity will spread over a surface of 25 square feet $2\frac{1}{2}$ inches deep, which is about the thickness found best in practice. Where however economy is not the first consideration, this thickness may be decreased, and the surface proportionally extended, for the greater the surface the more effectual is the purification. The lime must be laid of a very even thickness upon the screens, otherwise the gas will pass with greater rapidity through the thin than through the thick parts, and in time work holes, so that it will hardly be affected by contact with the lime.

Carbonic acid*, as well as sulphuretted hydrogen, is removed by this purifying process, and the gas now only retains ammonia, and the fatty oils which are taken up by the "scrubber," to be described further on.

In Plate XII. Figs. 1 and 2, are represented an elevation and plan in section of one of a series of three "dry-lime" purifiers, through which the gas passes successively; in other words, they are "worked together," and, though separate, may be considered as one machine.

A is the inlet-pipe from the wash-vessel, entering at the bottom of the first purifier.

B is a plate of sheet-iron, about two feet square, placed over the mouth of the inlet-pipe, to separate the stream of gas in some degree, as well as to prevent any lime from falling into the pipe.

C C C are the layers of hydrate of lime, spread upon screens formed of an outside frame, and a number of round rods or wires about $\frac{5}{16}$ of an inch in diameter, stretched across them in one direction, to afford greater facility for clearing, with a small interstice between each. These screens are placed one over another, in three tiers, from six to eight inches asunder; each tier may consist of four screens, for the convenience of lifting them out and replacing them.

D is the outlet-pipe leading to the second purifier†. This arch-pipe is made of

* If the gas contains more than 3 per cent. of carbonic acid, a further operation is required for its removal, as explained at page 34.

† The machines now made have a tight partition fixed so as to divide them into two equal divisions, as shown in Fig. 25*; the inlet gas passes from bottom to top on one side of this partition, and the outlet takes the contrary direction on the other side: this improvement allows of the outlet-pipes being carried from the bottom, which is an advantage.

thin plate-iron, sealed at each end by a water-joint; because, when the lid has to be lifted, this arch-pipe must be removed, and any other kind of joint would be troublesome.

E is the lid of the purifier, also sealed by a water-joint; *e e* are round $\frac{5}{8}$ rods, keyed at one end into the keep-ring *k*, and riveted to each corner of the lid at the other; a chain is hooked on to the ring *k*, and passed over a pulley to a balance-weight, by which, and the rods just mentioned, the lid is lifted. When the pressure upon the lid is greater than that within the purifier, great force would be required to raise it, if no means were provided for equalizing the pressure: for this purpose doors are provided, which can be removed at pleasure; they must be open as well when the lid is lowered as when it is raised.

F F are blank flanches or bonnets, through which, when removed, the pipes are cleared from any deposited impurity.

G G are clamps to keep the lid of the purifier in its place. The general arrangement of the purifiers will be more fully explained by reference to Plate XIII., where the two sets are shown with their several pipes and valves.

A is the pipe leading from the wash-vessel into one partition of the hydraulic valve, which I shall describe immediately.

B is the pipe leading to the three purifiers C D E in action, and rising into the same partition of the valve as B.

F is the pipe leading the purified gas back to another partition of the valve.

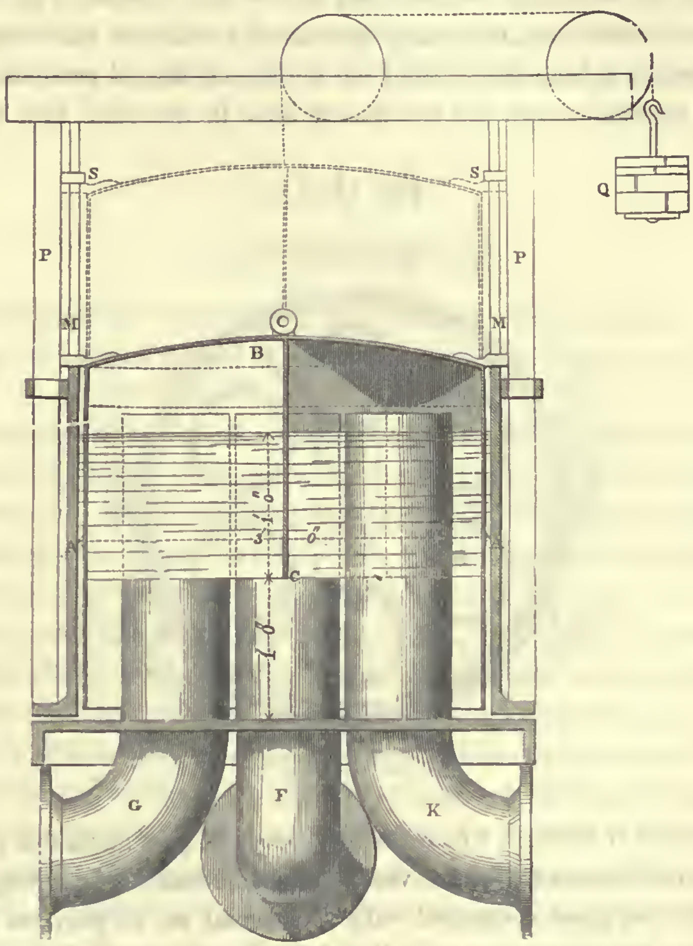
G is the pipe conveying this gas to the meter and gas-holders; the connection between the two last-named pipes is formed in the same way as that between the pipes A and B. It will be evident that the lime contained in the first purifier will be spent or saturated before the other two, and that contained in the third will be comparatively untouched. At the expiration of twenty-four hours C, D, and E must be shut off, by changing the divisions of the hydraulic valve to the situation shown by the dotted lines in the figure representing that valve, and turning the gas through H I K, having previously been put in readiness; at the instant of turning the valve the gas will pass through both sets of purifiers, all the communications being open.

When the covers of C, D, and E are taken off, remove the screens from C, and place those from E in their stead. The lime from C is quite expended, and must be either heated to sublime the sulphur, or laid aside until it can meet with a sale as manure, or be otherwise disposed of. That from D may be spread for a time in the open air (if there be room in the works), and in a week or two it will be fit

to use in the first purifier. After renewing the lime in the second and third purifiers, replace the covers, and they are again ready for action. The same operation is repeated when H, I, and K are spent.

The annexed woodcut represents the hydraulic valve just mentioned.

Fig. 25 (1).



A is a cast- or sheet-iron tank, three feet diameter and two feet six inches deep, generally filled with tar to within six inches of the top.

B is a light sheet-iron or tin gasholder-shaped vessel of less diameter, divided into three partitions by the plates C, D, and E, of less depth than the rim.

F is the pipe from the wash-vessel or condenser.

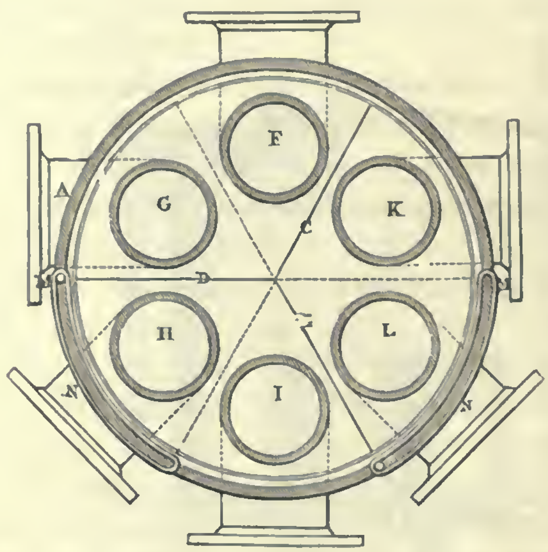
G is the pipe leading to the first set of purifiers.

H is the outlet or return pipe from them.

I is the pipe leading to the meter and gas-holders. These pipes, in the present position of the valve, are all in action.

F and G being in the same partition communicate with each other, as do H and I, for the same reason. When the purifiers have to be changed, the vessel B is lifted up, until the bottom of the partition, at C in the elevation, Fig. 25 (1), clears the pipes, the outside rim remaining immersed in the tar (the stops S on the guide-rods prevent it from being lifted too high), and turned partly round until it occupies the position shown by the dotted lines in the plan, Fig. 25 (2). The

Fig. 25 (2).



length of each dot N through which the guide-rods M pass mark this position, and effectually prevent mistakes, for the vessel cannot be turned the wrong way.

K and L are the pipes connected with the second set of purifiers thrown into action and into communication with F and I, when the vessel B is shifted to the position shown by the dotted lines in the plan.

P is a wooden frame supporting the pulleys and balance-weight Q to assist in lifting the vessel B, which, while in action, is kept from rising with the pressure of the gas by a bolt.

The arrangement of valves connected with this part of the apparatus is of consequence. One hydraulic valve is decidedly preferable to four or more slide-valves,

because if the man whose duty it is to attend to them were to shut those leading to the spent purifiers before he opened the others, the consequences would be serious; the sudden check given to the exit of the gas from the retorts would drive the tar from the hydraulic main up the dip-pipes into the open retorts, if there happened to be any, and most probably do much injury. I have myself witnessed several accidents from this cause. With the one hydraulic valve this cannot occur, for it is impossible to close one partition without opening another. They are much cheaper, less liable or not liable at all to be out of order, and altogether more advantageous.

PLATE XIV.

LIME-WATER PURIFIER.

I will now proceed to the subject of purification by lime-water.

Fig. 1 is an elevational section of a lime-machine, and Fig. 2 a plan through *a b* in Fig. 1.

A is the inlet pipe through which the gas passes into the chamber B, which is four feet diameter, jointed to the lid of the purifier, and supported upon two cast-iron beams C. On to the bottom flanch of this chamber a circular ring of thin wrought-iron plate is riveted, of such a diameter that its outside rim will be within five inches of the tank of the purifier.

D is a hoop supported from the tank by bolts *d d*, etc., having its upper edge level with the before-named plate, and its lower edge four or five inches below it. The space left between this hoop and the ring is three-eighths of an inch, through which the gas (after having overcome the pressure of the column of water contained in the tank, *plus* the pressure in the gasholders) will pass, and bubble up through the lime-water.

E is an arm made to revolve on the spindle S: the parts *e e* of this arm continue through the aperture and over the ring, serving to keep the lime from settling or obstructing the passage of the gas.

F is the outlet for the purified gas.

G is a stuffing-box, through which the spindle S passes.

H a mitre-wheel, connected to a water-wheel or steam-engine, for turning the spindle.

I is a pipe, through which the lime-water is drawn off when it has become saturated with the impurities of the gas. It will be observed, that by this con-

trivance the water can be completely drained off, by opening a slide-valve bolted to the flanch of the pipe K, without suffering the gas to escape along with it, because a column of water will remain in the tube I equal to the height of the bottom of the tank, measured from the inner radius of the curve of the tube, viz. twelve inches, which is always more than sufficient to overcome the pressure of the gas in the purifier when the valve on the inlet-pipe A is closed, which should be done before that at K is opened.

L is a cylindrical vessel, open at the top, for filling the purifier; it also serves to show the quantity of water required; when the machine is at work the column contained in the vessel will be as much higher than that in the tank, by the pressure of gas in the gas-holders, usually about three inches.

The explosion at Peter-street, mentioned at page 17, was occasioned by the gas escaping with the lime-water, no sealing-tube being attached.

The lime-water may be mixed in a cistern (having its bottom *above* the level of the water in the purifier when filled, and furnished with an agitator worked by hand), and drawn off by a hose into any of the machines, care being taken to keep the mixture well agitated while passing. The proportions are one measure of paste-lime to three of water; that is, to every five bushels of paste-lime about 120 gallons of water must be added. The size of the lime-machines ought to be so regulated that they will contain sufficient lime-water to purify the quantity of gas made in twenty-four hours, without having occasion to fill them higher than the water-line shown in the engraving.

Four lime-machines are necessary, two being in action and two out, alternately. When that machine is spent through which the gas first passes, shut it off, and open a third, leaving the second to perform the duties of the first, and so on. The following extract from Mr. Clegg's Journal will give his opinion on the construction and use of lime-machines:—

"The grand principle of the construction of a lime-water purifier is to divide the gas as minutely as possible, at the same time avoiding unnecessary pressure. If the machine be well constructed, seven or eight inches' pressure in each machine is quite sufficient. Two sets are necessary, in order to have a pair clean and ready for immediate use. The practice of working the contents of the vessel over again, by passing them from one to another, is mistaken economy."

From the retorts contained in the building represented in Plate IX. 300,000 cubic feet of gas may be produced in twenty-four hours. The purifiers should present a surface of at least 750 square feet. If three machines are worked to-

gether, each containing five screens, their dimensions may be 8 feet 6, by 6 feet, and 3 feet deep, four bushels of hydrate of lime being spread on each screen. The surface presented by the three machines in Plate XIII. is 324 square feet: they were erected for an establishment producing 130,000 cubic feet of gas in twenty-four hours.

The work performed by a lime-water purifier is generally computed by its contents in gallons, and the head of water or pressure opposed to the passage of the gas through it. Taking the latter at a constant quantity of eight inches, the computation is easy. 4500 cubic inches of hydrate of lime (which has been before stated is the quantity produced by reducing one bushel or 2150 cubic inches of quicklime), mixed with forty-eight gallons of water, will purify 10,000 cubic feet of gas, if properly applied. In the example at Plate XIV. the lime-machine contains 316 gallons, which will hold in solution thirteen bushels of hydrate of lime, and purify 65,000 cubic feet of gas. Two of these machines will therefore do the same work as the three dry-lime purifiers before mentioned, viz. 130,000 cubic feet.

To reduce the operation of one of these machines to theory, the gas should be so divided that each atom of sulphuretted hydrogen should be brought into close contact with its equivalent atom of lime; the chemical change would then be effected instantly, a hydrosulphuret of lime being formed, and the depth of water holding the lime in solution need not exceed that of a single atom. It is impossible practically to effect this perfect contact, but we can approach in some considerable degree towards it, by allowing the gas to pass through the liquid only in small bubbles, which is effected by the ring and plate touching each other within half an inch, the gas being made to pass through this annulus. In some machines the gas is allowed to pass through the lime-water in masses, as it would escape from under the plate if no ring confined the space: *then* the purification would not be effected by double the pressure, for the chemical reason that the atoms of sulphuretted hydrogen would not be brought into contact with their equivalent atoms of lime; a quantity would therefore escape through the machine unchanged, and remain as an obnoxious impurity. The most essential thing then to be attended to in the construction of both dry and lime-water purifiers is *surface*.

Notwithstanding however that the quantity of lime required may be well known, it is necessary to *test* the gas in its progress through the various purifiers. In some cases it is advisable to use the test every twelve hours, or oftener, in districts, for instance, where coal is of inferior and various qualities. Every morning, as soon

as the superintendent arrives at the works, he ought to test the action of his purifiers, more especially if he has received a fresh supply of coal or lime. A saturated solution of the acetate of lead in distilled water is an excellent test, detecting the presence of the minutest quantity of sulphuretted hydrogen, and more convenient than the carbonate, from its complete solubility. Test-papers may be printed in the following form:—

Station and Date.

Crude Gas.	1st Purifier.	2nd Purifier.	3rd Purifier.

Lime-machine having been charged hours with bushels of lime.

The paper of the 3rd purifier should remain colourless.

Mr. Alexander Croll, the engineer of the Great Central Gas Consumers' Company, has taken out a patent for freeing gas from its ammonia, and a part of the sulphuretted hydrogen, producing at the same time muriate of ammonia. He introduces a solution of the muriate of zinc into a vessel, upon the same construction as a wet-lime purifier; on admitting the gas, double decomposition ensues; an insoluble sulphuret of zinc and a solution of muriate of ammonia are produced. The gas must be further purified with lime, in the usual way.

For the removal of the ammonia and the sulphuretted hydrogen by one and the same process, a new method of purification has been adopted, and is one well worthy of confidence. The screens of the purifiers are covered with a mixture of carbonate of lime and sulphate of iron: these, reacting on each other, become carbonate of iron, and sulphate of lime; by exposure, the carbonate of iron absorbs oxygen from the air, leaves its carbon, and becomes partly peroxide of iron. The gas, streaming through this mixture (peroxide of iron and sulphate of lime) gives up its sulphuretted hydrogen to the oxide of iron, forming sulphide of iron and water, while the carbonate of ammonia (contained also in the impure gas) decomposing the lime-salt, forms sulphate of ammonia and carbonate of lime.

When the purification is completed, and the mixture has done its work, it is exposed to the air, and the sulphide of iron absorbing oxygen, is converted into a basic sulphate of iron. Hence we have the same mixture as at first, viz. carbonate of iron and sulphate of lime, with the addition of sulphate of ammonia,

which may be washed out and preserved, while the residue is employed over and over again. By this elegant process the noxious sulphur compounds are utilized in the fabrication of sulphate of ammonia, and the mixture seems never weary of performing its duty; hence not only is the purification performed at one process, but the noxious ingredients are converted into compounds of much value.

Another method of removing ammonia may be noticed: it consists of spreading on the screens superphosphate of lime, consisting of bones dissolved in sulphuric acid; the addition of ammonia to this makes it a powerful and excellent manure.

"The waste and badly-smelling products of gas-making appeared almost too bad and fetid for utilization, and yet every one of them, chemistry, in its thriftiness, has made almost indispensable to human progress. The badly-smelling tar yields benzole, an ethereal body of great solvent powers, well adapted for preparing varnishes, used largely for making oil of bitter almonds, of value for removing grease-spots, and for cleansing soiled white kid gloves. The same tar gives naphtha, so important as a solvent of India-rubber and gutta-percha. Coal-tar furnishes the chief ingredient of printer's ink, in the form of lamp-black; it substitutes asphalte for pavements; it forms a charcoal, when mixed with red-hot clay, that acts as a powerful disinfectant. When the tar is mixed with the coal-dust formerly wasted in mining operations, it forms by pressure an excellent and compact artificial fuel; the water condensed with the tar contains much ammonia, readily convertible into sulphate of ammonia, a salt now recognized as being of great importance to agriculture, and employed in many of the arts. Cyanides are also present amongst the products of distillation, and these are readily converted into the beautiful colour known as Prussian blue. The naphthalin, an enemy to the gas-manufacturer, by choking the pipes, may be made into a beautiful red colouring matter, closely resembling that from madder; this, by its transformation, promises an important, though hitherto not yet realized useful product. Coal, when distilled at a lower temperature than that required to form gas, produces an oil containing paraffin, largely used as an anti-frictional oil for light machinery*."

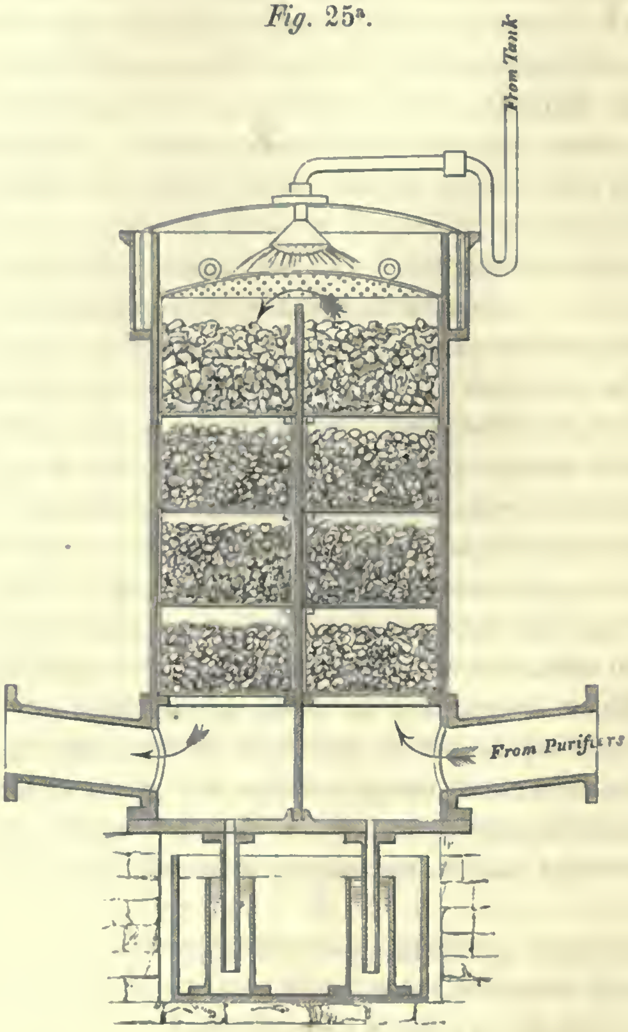
I may here state that naphthalin, produced largely when coal is distilled at too high a temperature, is olefiant gas in a solid state, and that the coal-oil mentioned by Dr. Playfair is this gas in a liquid state; so that this gas is alone gained in an aeriform condition when a proper heat is applied.

* Lecture delivered by Dr. Lyon Playfair, C.B., F.R.S., before the Society of Arts, January 7, 1852.

SCRUBBERS.

The action of these machines is partly chemical and partly mechanical; they may be made precisely in the same form as a dry-lime purifier, but are better in the form shown in Fig. 25ª. The screens are covered with layers of small coke,

Fig. 25ª.



furze, or any insoluble material, presenting a large surface to the passage of the gas. The scrubbing material is kept moist by water gently showered on to it through

the siphon and rose on the top of the vessel, which runs off through the sealed pipes at the bottom. One cubic foot of wet scrubbing material is generally ample to remove the tar and fatty oils from 1000 cubic feet of gas, which it is the object of this machine to effect. In the event of naphthalin becoming troublesome, coal-naphtha may be showered over it instead of water. This naphtha may be pumped from the tank beneath the scrubber, and re-used: the seal-pipes are arranged to allow of this. Very dilute sulphuric acid, or rather water made slightly acid to the taste, is very effective in removing the ammonia, sulphate of ammonia being formed. The fatty oils adhere to the coke, etc., and probably a porous material may be preferable to a close one for this adhesion.

If the crude gas has been thoroughly condensed, the scrubbers are placed after the purifiers; but if there is the least chance of tar remaining up to these machines, the gas must be scrubbed before it is allowed to enter them, because the tar would form more or less under-coatings to the layers of lime, and prevent their proper action. But the safest arrangement undoubtedly is to place a dry or a simple water-scrubber between the condensers and purifiers, and a second one supplied with acidulated water after the purifiers. It is not necessary in small works to have a change of these machines, their cleansing and the renewal of the coke, etc., occupies but a short space of time, and a side-pipe may be arranged so as to take the gas past them during the operation.

In works of moderate size the capacity of the scrubbers may be increased so that the material may only require renewing once a week, or even at longer intervals. The lids must furnished with air-doors, similar to those described for purifiers.

GAS-METERS.

Before passing the purified gas to the gas-holders, it is necessary that it should be measured and its quantity registered, which operations are effected by the *Meter*. Of this valuable machine there are two kinds,—the *Station-Meter*, for measuring the total products of gas at the works before it is supplied to the mains; and the *Consumers' Meter*, for measuring small quantities as supplied to individuals.

It is of the former I now propose to speak. Its advantages are so well known and so generally appreciated, that it would be superfluous to enter into any lengthened enumeration of them; I shall therefore confine myself to a more practical consideration of it.

In Plate XV., Fig. 1 is a front elevation in section; Fig. 2 is a side elevation, also in section, of a station-meter of the capacity of 200 cubic feet, by which 300,000 cubic feet of gas may be measured and registered in twenty-four hours.

The principal part of the machine consists of a hollow drum of thin sheet-iron A A, revolving upon an axis *a*, and divided into compartments, so arranged that, as the gas enters, it shall in revolving successively fill all the chambers, pass through them, and be discharged measured.

The part of the drum which contains the gas is in the form of a concentric ring, one foot six inches broad, and six feet deep, and seven feet six inches in extreme diameter, which will be understood by reference to the engraving. The plates which form the sides are of the same outer diameter as the drum, viz., seven feet six inches, but are two feet nine inches broad; they will therefore project within the smaller diameter, leaving the centre circle (through which the inlet-pipe K passes) two feet in diameter. The surface of the water contained in the drum and outside tank of the meter, is four inches above the upper circumference of this centre circle, when the drum is in its place; so that the communication between the outside and inside of the drum is cut off by a head of water of that height, and continues to be so in every part of the revolution. It is evident therefore that the gas must enter any chamber having its inner hood above the surface of the water.

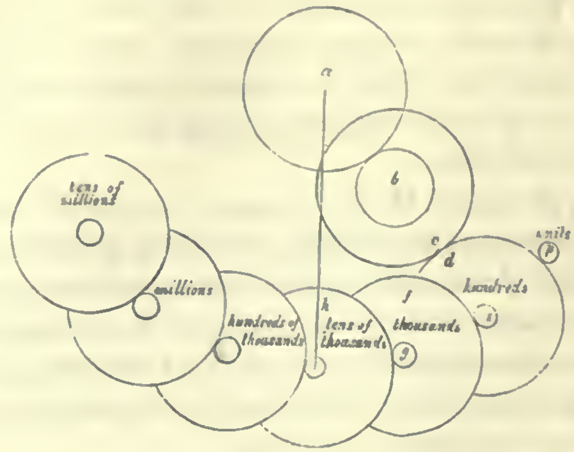
B C D E represent the inner hoods, and the direction of the gas from the inlet-pipe is shown by the small arrow at B. As the chamber fills with gas, it displaces the water, and causes the drum to revolve. Before B dips into the water, the hood C rises above the surface, and opens a communication for the gas into its chamber; and so on with D, E, when it will have completed one revolution, and measured 200 cubic feet.

The same action that allows the free passage of the gas *into* the chambers causes it to be expelled *from* them through the outer hoods F G H I, in the direction of the arrow at F: each of these outer hoods is sealed alternately in the same manner as the inner hoods, and opened for the passage of the gas from them, by one constantly being above the water-line. In setting out the hoods care must be taken to have them of a proper length. The direction in which the drum revolves is marked by the arrow over the top of the case.

The bevels of the division-plates *d d* are arranged so that they will enter the water without effort; and, for the convenience of workmen, they are generally made to slope towards the points where lines drawn at right angles through the centre of the axis would intersect the inner circumference of the drum, as *d m*, *d n*. The axis *a a*, on which the drum revolves, is supported on friction-rollers; on the front end of this axis a spur-wheel S is fixed, working into another wheel T, having half the number of teeth; at every half-revolution of the drum it will therefore make an entire revolution; its spindle passes through a stuffing-box, and is furnished at the opposite end with another wheel V, which marks 100 feet on the index. From a pinion on the spindle of this last wheel another wheel is worked, having ten times the number of teeth on the pinion, which will therefore mark thousands. This last wheel is again furnished with a pinion, and works into a third wheel, which will mark tens of thousands, and so on; the quantities marked on the dials increasing in a tenfold ratio up to hundreds of millions, or higher if thought necessary.

The entire train of wheel-work is shown in Fig. 26, where *a* is the first spur-wheel, working upon the main axis; *b* the second wheel, both being inside the meter-case; *c* is the wheel on the opposite end of the shaft of *b*, which projects through a stuffing-box on the case, in order to communicate motion to the train of wheel-work, on the outside of the meter-case; *d* is the wheel driving the hand which marks hundreds on the index, and having a hundred teeth (*c* has likewise the same number of teeth); *e* is the pinion on the wheel *d*, having ten teeth; *f* is the wheel driving the hand which marks thousands on the index, having

Fig. 26.



a hundred teeth, and driven by the pinion *e*; *g* is the pinion of the wheel *f* driving *h*, which marks tens of thousands on the index: in this manner any quantity may be registered. If it be required to register units (and in smaller meters it is useful), the first wheel *d* is made to drive a pinion, *p*, having ten teeth, to the spindle of which the hand marking units is attached.

The old contrivance of the "Tell-tale," when attached to the station-meter, becomes a valuable instrument, as it serves the purpose of effectually pointing out every irregularity that occurs in the production of the gas during any hour of the twenty-four. Suppose, for example, the superintendent desires to know whether his workmen have at any time during the day or night made the proper quantity of gas from the given quantity of coal: he may upon examination find all the retorts in an excellent working state; but whether they have been so at all hours, or whether the requisite quantity of gas has been really produced during the time that the pipes which convey it into the mains have been open, is to him a matter of uncertainty: the "tell-tale" will show him by inspection if any irregularities have occurred, and, if any, at what hour: this appendage may then be considered as a check on the conduct of the workmen. It may also be known what man or set of men have been negligent; for the retorts having their proper hours of work, will, if neglected, speak for themselves, and the men whose duty it is to look after them will be to blame.

It is thus constructed:—in the centre of the dial-field a circular plate is fixed, connected to the train of indicating wheel-work, and made to revolve in a certain ratio to the quantity of gas registered by the meter. Upon this plate a

sheet of paper is secured, divided, for example, into twenty-four parts, which parts may be subdivided. Suppose the meter to register 300,000 cubic feet in twenty-four hours, and the plate connected by wheels in the ratio of three to one to that index which marks a hundred thousand in one revolution, it is evident that the distance travelled by one of the twenty-four divisions of the plate from a certain fixed point will indicate the quantity of gas made in one hour, or $\frac{300,000}{24} =$ 12,500 cubic feet. Above this divided disc is a timepiece, to the minute-hand of which is attached a detend, furnished with a pencil made to press gently upon the disc by a light spring. As the minute-hand of the timepiece revolves, the pencil, by means of a guide fixed to the meter-case, is regulated, so that in the first half-hour it will make a vertical line upon the paper, in length equal to the diameter of the circle formed by the minute-hand, measured from the centre to the point on to which the detend is fixed; in the second half-hour the line will be retraced by the hand rising again. This is supposing the divided disc to be stationary; but as it revolves in the manner previously described, the pencil will make a series of curved lines, meeting the divided circle of the disc every hour, and the distance travelled from point to point will mark the number of cubic feet of gas made during every hour of the twenty-four. If the production of gas is regular, the figures formed by the pencil will be regular also; if, on the contrary, any negligence has occurred, the irregularity of the figure will detect it, pointing out the hour and the amount of difference; because, if the speed of the revolving disc be decreased, the figure formed will approach nearer to the straight line; if increased, the points of intersection upon the divided circle will be further apart.

By reference to the diagram (Fig. 27) the "tell-tale" will be understood.

a is the divided disc upon which the curved line formed by the pencil is shown.

b is the train of the wheel-work connected with the index marking 100,000.

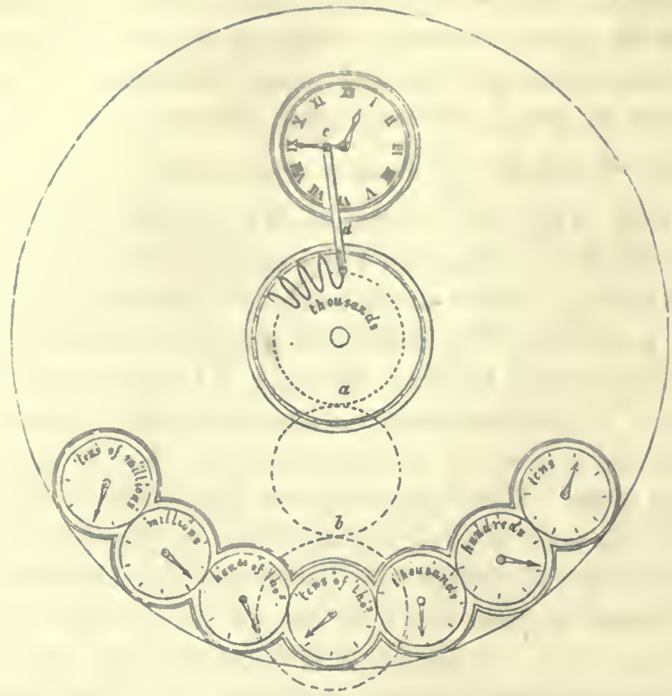
c is the timepiece and point at which the detend is attached to the minute-hand.

d is the detend, to the lower extremity of which the pencil is attached.

Mr. Lowe used this instrument at the Chartered Gas-works in 1823; it has since been adopted by many, but not so generally as it ought to be.

The consumer's meter is constructed upon precisely the same principle as that shown in Plate XV.; but the partitions of the drum are differently arranged, and placed in such a manner, that, as they reach the water, the surface presented shall be as small as possible, or the resistance offered shall be so gradual that the stream of gas flowing through the machine is uniform and constant. This is

Fig. 27.

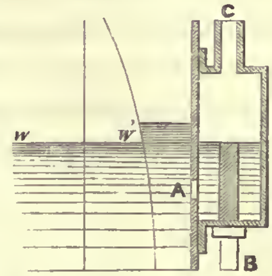


necessary in a meter from which any number of lamps are immediately supplied; because the most minute diminution or increase of the volume of gas flowing to them would cause a variation in the light, and produce an oscillation or "jump." In a station-meter the intervention of the gas-holder will remedy this defect. A variation in the arrangement of the drum therefore is a matter of necessity. The station-meter is formed for strength and durability, the way in which its drum is put together being more *mechanical* than that of the consumer's meter.

I have stated that the construction of the drum of the consumer's meter differs of necessity from that of the station-meter: it is so when the drum of the latter is made in the forms given in Plate XV. Station-meters are however sometimes made with drums like the smaller kind, but the *measure* will vary with every change in the water-line. If it is too high, the quantity marked will be too little; if too low, the quantity marked will be too great; these are circumstances to which the station-meter ought not to be liable, and which the form shown in the Plate completely obviates. Mr. Alfred King, of Liverpool, has used for some years a contrivance for maintaining the level of the water within the drum, and thus describes it.

"The height of the water within the drum determines the measuring capacity of the drum, but this height varies as the friction or resistance varies. To preserve a uniform level *within* the drum, I place, on the back of the meter, a small cast-iron box, into which the water from the meter is admitted at A. B is a pipe, screwed through the bottom of the box, so that the height of its open end may be adjusted. C is a gas-pipe connected with the *inlet*-pipe of the meter. By this arrangement the water-box will stand at the same level as it does in the drum. A small stream of water is allowed *constantly* to flow into the meter. If from increased friction the water is depressed in the drum, a corresponding depression takes place in the small box; but the constant flow into the meter soon restores the water to its proper level. If, on the contrary, the friction is reduced, then the water will rise in the drum and in the box, but the level is again restored by the surplus running off through the pipe B. I have only to add, that B is 'siphoned' below in such a manner as to allow of its being turned for the purpose of adjusting its height."

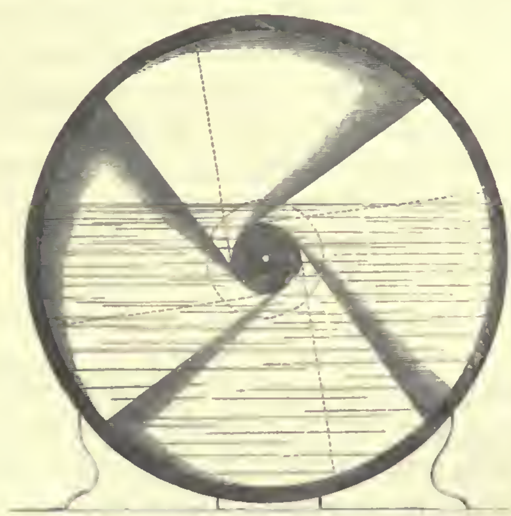
Fig. 27ª.



W W' level of water inside of drum.

By referring to the annexed figure the construction will be understood.

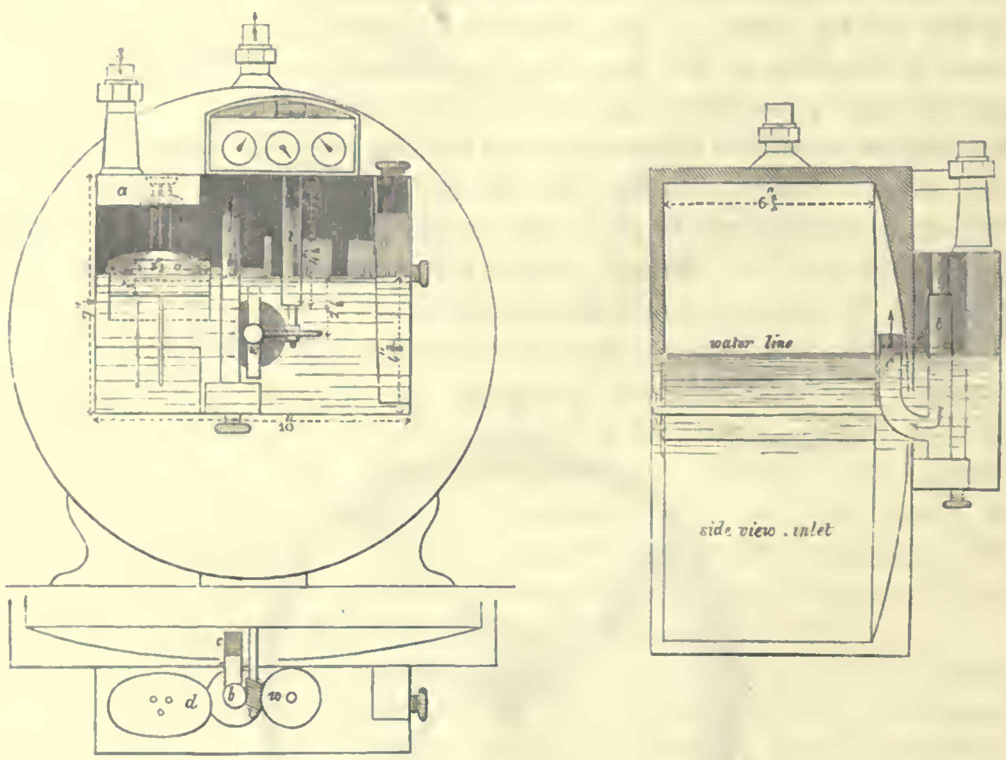
Fig. 28.



As in the former case, the outer circumference or rim of the drum is divided into four partitions, separated from each other by partition-plates, not running across

directly at right angles with the face, but beveling from the plane of the water, meeting the wrap of the opposite hood. The sides of these partitions are also beveled; the space left between each plate forming, on one side of the drum, the inlet, and the other side the outlet for the gas; the area of the latter being greater than the inlet, to ensure perfect freedom of action. The dotted lines in Fig. 28 show the wrap of the hoods; this figure represents a view of the front or inlet side of the drum, with the convex cover removed. The outlets will present the same appearance, but of course reversed. By referring to Fig. 29, representing a ten-light

Fig. 29.



meter, the remaining parts will be understood. The direction of the gas is marked by arrows. The box *a*, in which the inlet-valve is contained, is soldered tight, having no communication with the rest of the case, except through the valve, the position of which is shown by the arrows; *b* is the inlet-pipe projecting above the water-line, conveying the gas into the meter by the bent arm *c*, rising above the water between the convex cover and the inlet-hoods; *d* is a float attached to

the inlet-valve, adjusted so that when the water falls below the centre opening, the valve will close and the gas cease to enter the meter.

Motion is communicated to the train of wheel-work behind the index from a spiral worm *w* fixed on to the axis of the drum, working into a wheel, the spindle of which passes through the tube *t*, sealed by dipping under the water contained in the case.

The following are the principal dimensions of consumer's-meters:—

Number of lights	5	10	20	30	50	80	100	150	200	400	800
Diameter of drums ...(inches)	$12\frac{1}{4}$	$14\frac{3}{4}$	$17\frac{1}{2}$	$19\frac{1}{2}$	$21\frac{1}{2}$	25	$27\frac{3}{4}$	33	33	44	60
Depth „ „ ...... „	5	$6\frac{3}{4}$	$9\frac{1}{8}$	$10\frac{7}{8}$	$11\frac{3}{4}$	$12\frac{3}{4}$	$13\frac{3}{4}$	$20\frac{1}{4}$	$24\frac{3}{4}$	$30\frac{3}{4}$	$40\frac{1}{4}$
Diameter of water circle „	$3\frac{1}{4}$	$3\frac{3}{4}$	$4\frac{1}{2}$	5	5	$6\frac{1}{2}$	$7\frac{1}{2}$	9	10	15	21
Centre opening .... „	$1\frac{3}{4}$	2	$2\frac{3}{4}$	3	$3\frac{1}{4}$	4	5	6	7	10	15
Hollow cover projects „	$\frac{3}{4}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$3\frac{1}{4}$	$3\frac{3}{4}$	$4\frac{3}{4}$
Depth of inner hoods... „	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	1	1	$1\frac{1}{2}$	2	3	5
„ outlet „ ... „	$\frac{3}{4}$	1	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	4	$5\frac{1}{2}$
Capacity in cubic feet	·25	·50	1·00	1·50	2·00	3·00	4·00	8·00	10·00	20·00	50·00

The inlet-hoods are those under the convex cover, or the inlet openings for the gas, and the dimensions given are extreme depths at the circumference of the drum. The outlet-hoods are for the escape of the gas into the meter-case. Dimensions given for the same part.

In setting out the wrap of the hoods over the division plates, care must be taken to have them of the proper length, which will be, when the water is just touching the outer end of the inlet-hood, the outlet-hood of that division must be clearing the water. If the hoods are too long, it will prevent the gas from escaping from that division which is entering the water; and if the hoods are too short in the wrap, the gas will blow through, and the meter stand still.

CLEGG'S NEW GAS-METER.

There are many disadvantages attendant upon the use of the meter just described. If the water varies in level the measure will vary; if the water freezes, the meter will stop; a considerable pressure is required to work the drum; and leakages very frequently exist in them, which suffer the gas to escape to the burners without being measured. By reason of its unsightly appearance and its bulk, it is generally placed in a cellar or some place where it may be hidden from view; it is therefore almost always subject to influence from atmospheric changes, and the consumer is prevented from knowing what quantity of gas he is burning,

unless he pays a special visit to the place of its deposit*. Moreover the present meter is a costly article.

No one was more aware of these defects in his instrument than the inventor; and he has therefore for years been endeavouring to arrange a gas-meter that shall have none of them; he has at length succeeded, and the following description, with the aid of figures 29ª and 29ᵇ, will enable it to be understood.

Fig. 29ª.

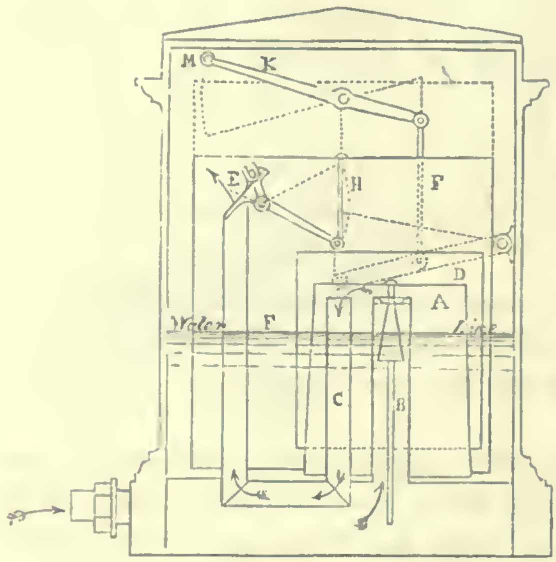
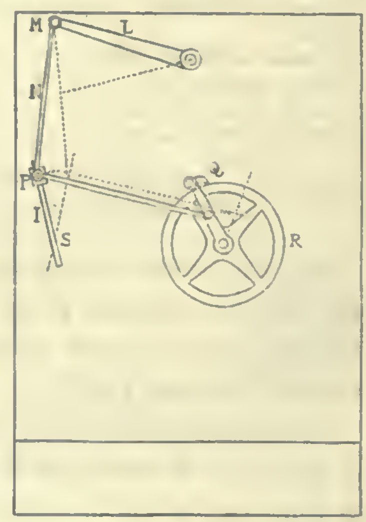


Fig. 29ᵇ.



The most certain means of obtaining a correct measure of the quantity of any fluid, whether liquid or aeriform, is by passing it through an opening; the pressure causing it to flow being perfectly uniform, the quantity is as the area of the opening, certain allowances being made for the difference of friction offered by small and large openings: for since the sides of a small opening present a greater rubbing surface in proportion to its area, than do those of a larger opening, their influence upon the free discharge of the fluid, or the friction, will be greater.

The difficulty of causing gas which enters a meter with a constantly varying pressure to assume one perfectly uniform, when passing the measuring opening,

* The dry meter, which has of late years been so much used, obviates many of the disadvantages of the water-meter, but it has defects peculiar to itself, which are of a nature quite as serious, the chief being the speedy destruction of the diaphragm, and consequently that of the instrument as a measure.

was the cause of many anxious delays, but the successful means adopted is most simple and efficacious.

The gas entering the meter from the street-mains is conveyed into a governor A, floating in water, which, rising or falling with the varying pressure of the gas, decreases or increases the area of the opening admitting it, by means of a cone, whose sides approach or recede from the circular seat on the mouth of the inlet-pipe B, thus increasing or decreasing the space above the water-line, and reducing the gas to one uniform density, permitting it to flow through the pipe C at an unvarying pressure. That the governing hood, A, may work accurately, it is so adjusted as to be of equal weight at all points of immersion, and is covered by a vessel, D, connected with the external atmosphere.

The gas now passes through the measuring opening, over which a slide, E, works, increasing or decreasing it, according to the quantity of gas flowing to the burners: the slide is thus worked :—

A superior vessel or hood F F, accurately balanced, and in communication with the external air, is placed over the opening or valve, so that the gas is discharged into it, and this vessel rises or falls in accordance with the quantity of gas drawn from it to the burners; the lever G and rod H, attached to the hood, communicates motion to the slide E. If no burners are lighted, the gas entering will fill the hood, cause it to *rise* to the full extent of its motion, lift the lever G, so that it will occupy the position shown by the dotted line, and shut the valve; when one burner is lighted, a portion of the internal pressure is removed, and the hood will fall to a certain extent, and open the valve in proportion; when all the burners are lighted, the hood will *fall* to the full extent of its motion, occupy the position shown in Fig. 29[a], and open the valve wide; and the quantity of motion of the hood and valve will always be in proportion to the number of burners lighted. The area of the valve opening, being adjusted by previous experiment to the total quantity of gas the meter is intended to register, will thus become an unerring measure for all less quantities as well; because the pressure is always uniform, and the area of the opening in exact proportion to the quantity of gas discharged through it.

It now remains to be shown how the motion of the valve is communicated to the train of wheel-work forming the index of the meter.

A clock spring and fusee gives motion to a vibrating arm, I, the speed of which is always perfectly uniform. The lever K is attached to that worked by the hood F, and its end M is of the same stroke. The lever L, Fig. 29[b], works on the same

2 E

shaft as K, and has the same extent of motion. Upon the vibrating arm I, a loose ring, P, attached to the lever L by a rod, slides up and down with the rise and fall of the lever: the ring P is united to a detend and pall, working into the teeth of a ratchet-wheel, R; the number of teeth taken, or the extent of the revolution of the ratchet-wheel, depending upon the space passed through by the ring P, and this space will depend upon its distance from the centre of motion S of the vibrating arm. Now I have explained that the greater the quantity of gas drawn off from the hood F to the burners, the lower it will fall, and the higher will rise the end M of the lever K and L; the path of P being also regulated by the same levers; it also will be taken further from the centre of motion, as more gas is drawn off, and drive round the ratchet-wheel in proportion. When the hood F is up to the full extent of its stroke, the lever L will take the position of the dotted line, P will be at the centre of motion of the vibrating arm, and communicate no movement to the ratchet-wheel; and thus is a perfect means of registering the quantity of gas flowing through the valve gained. The worm on the shaft of the ratchet-wheel, giving motion to the train of wheel-work constituting the index, is the same as in other meters.

When the clock movement stops, it is necessary to shut off the gas from the burners, otherwise of course no measure would exist, and this is done by the first wheel of the clock lifting a valve from time to time so contrived, that it shall not fall into its seat in the intervals, but very nearly, but the lifting wheel ceasing to revolve, suffers it to fall and shut off the gas. This valve is not shown in the figures, because it is only a precautionary part of the instrument, does not in any way affect the meter, and is therefore needless to describe.

It will be perceived that the level of the water-line may lower considerably without causing any inconvenience, for the water is only required as a seal to prevent the gas escaping from beneath the moveable vessels A and F, and is not at all connected with the measuring.

The advantages attending the new meter are as follow:—

1. It is more correct; the measure does not vary with the level of the water-line; leakages are not likely to occur, and consequently the results will not vary from this cause either.

2. The burners from the new meter are maintained with a uniform height of flame, whatever may be the varying pressure of the gas in the street-mains, and whatever number of lamps are turned off or on.

3. By reason of all the principal moving parts working in atmospheric air, it is not subject to wear and tear from corrosion, it is therefore more durable.

4. It can be taken to pieces and cleaned when necessary, and put together again in a few minutes without solder; or if from time any one of the parts has worn out, a new part can be substituted without involving the necessity of a new meter.

5. It is contained in a much smaller space, and can be made as ornamental as a timepiece if required, and it may always be placed in a shop-window, counting-house, or other conspicuous place, where the consumer can see his daily consumption of gas.

And lastly, it is cheaper than the old descriptions of meter, the larger sizes not costing more than one-half.

GAS-HOLDERS.

The simplest and most general kind consist of an iron vessel, open at the bottom, and inverted into a tank of water below the surface of the ground, having perfect freedom to rise and fall, and guided by upright rods fixed at several points in the circumference. The diameters and numbers of the vessels will vary according to the magnitude of the works to which they are attached, and the space to be occupied by them. If the works are situated in a town where ground is too valuable to allow an increased extent, "Telescope Gas-holders" are used.

The construction and management of Gas-holders I now propose to explain.

Plate XVI. represents the section of a gas-holder, capable of containing 150,000 cubic feet, the diameter being eighty-seven feet six inches, and height twenty-five feet. The sides A A are made of No. 16 iron-plate (Birmingham wire-gauge), weighing $2\frac{1}{2}$ pounds to the square foot, riveted together; the top, B, of plate weighing about three pounds to the square foot, or No. 14 gauge.

C C, etc., are rings of three-inch T iron, placed five feet asunder, and riveted strongly to the sides; the rivets ought not to be more than three inches apart. The top and sides are secured together by three-inch angle-iron, rolled to fit the curve, as shown in the cut.

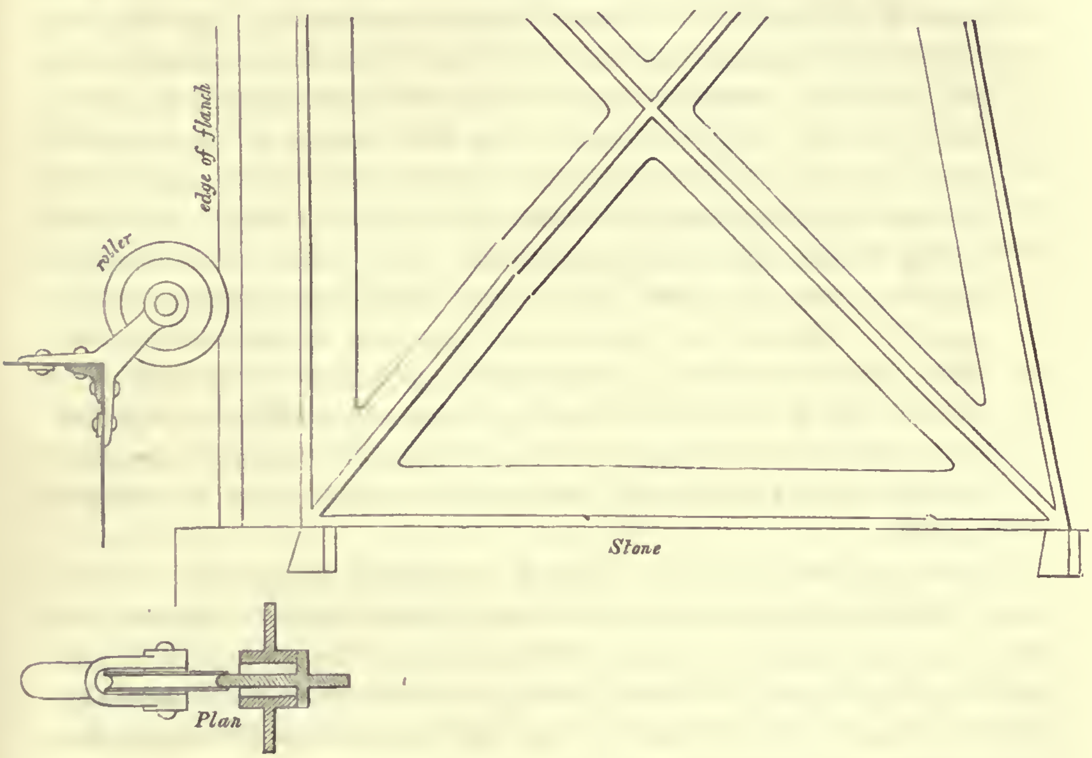
d d are rings of bar-iron, about half an inch thick and three inches deep, fastened to the top by clips, which are riveted; these rings are placed about six feet apart, and strengthened further by diagonal bars, from one to another, breaking-joint.

E are stays formed of wrought-iron pipe, about $1\frac{1}{2}$ inch diameter, fixed in the situations represented in the Plate, their ends being bolted to the T iron at the sides, and the rings on the top.

G are vertical rods, fixed at their upper and lower ends to the brickwork of the tank, and being passed through eyes fast to the bottom of the side of the gas-holder, serve to guide the vessel in its rise: their positions are between the standards S, on which are also guide-rods acting in like manner. The eyes serve as stops to prevent the vessel rising out of the water.

The standards S, eight in number, are each formed of three cast-iron frames, six feet broad at their bases, of the same height as the gas-holder, and jointed together in the form of a T, as in plan; they are secured to the stone (marked in the engraving) by dovetailed lock-nuts, keyed and leaded, as represented in the figure.

Fig. 30.



Preference is often given to rollers, instead of rings, for guiding the rise of the gas-holder, and perhaps as there is less friction they may be more advantageous; their only inconvenience is the liability of their coming out of the guides. I have shown a roller in the cut which works against the flanch of the centre standard, widened for that purpose.

H is the wooden curb, which ought always to be attached to a gas-holder; its use is to regulate the flow of gas from one gas-holder to another. While immersed in the water of the tank it acts as a float, and, to some extent, buoys up the vessel; when the gas-holder has risen to its full height, it acts as a

weight, being partly *out* of the water, thus causing the gas to flow into another gas-holder not yet full, and which, having its curb completely immersed, is under less pressure. For example, suppose the weight of the gas-holder to be thirty-three tons, and its working pressure to be $2\frac{4}{10}$ inches; suppose also the weight of the curb in water to be $2\frac{1}{2}$ tons, then, when it partly rises out of the water, the working pressure will be increased by the weight of so much of curb in air *plus* $2\frac{1}{2}$ tons, *minus* the buoyancy of so much as yet remains in the water (which ought not to be more than two inches): this increased pressure will be found to be nearly four-tenths of an inch, and quite sufficient to cause the gas to flow into another gas-holder, having its curb totally immersed. The mains leading to the gas-holders ought to be all open, and the gas unrestricted by valves, which ought only to be closed when a gas-holder is undergoing repair; even then I should prefer sealing its inlet- and outlet-pipes by water; for let there be any number of gas-holders, even of the same diameter and height, their weights, and consequently the resistance they oppose to the entrance of the gas, will vary something; therefore they will not fill equally; the lightest will rise first, and if the next has an excess in the working pressure of a little more than four-tenths of an inch, it will not rise at all until the curb of the first is completely in action, which I have already shown will be in effect equal to four-tenths of an inch.

All the gas-holders should be regulated by weighting them, adding to or reducing their curbs, so that they will not vary in their respective pressures more than about three-tenths of an inch. If the capacities of the gas-holders be made equal to the produce of gas in twenty-four hours, and the above simple precautions taken, no inconveniences will arise; no gas will be lost, or accidents occur, from negligence on the part of workmen.

The dimensions of the curb H will be 12 × 12 inches, formed of Memel timber, scarfed and fastened together in segments by trennels, and secured to the sides of the gas-holder within three inches of the bottom, so that when it is out of the water ten inches, the sides may be sealed by a head of water five inches, more than is actually necessary, but, completely to guard against accident, not more than advisable.

I is the inlet-pipe, of the same diameter as that leading from the retorts, viz. eight inches. Its mouth above the water-line should be rather higher than the edge of the tank.

K is the outlet-pipe, twelve inches diameter, entering the gas-holder under the same circumstances as the inlet-pipe.

L are receivers, in which the tar or water collects from the mains, being pumped out by a small hand-pump, of which *a* and *b* represent the suction-pipes.

The well, down which these pipes are conducted, may be about seven feet diameter, built of brickwork in cement, and well puddled, and as much lower than the tank of the gas-holder as to allow the top of the receiver to be below the bottom of the tank. The tank of the gas-holder may be built of brickwork in mortar; in good ground the dimensions marked in the engraving, with a counterfort every ten feet, projecting eighteen inches, will be strong enough. Care must be taken however to have good, sound, and well-burned stock-bricks. The outside of the tank, to the thickness of two feet, must be well puddled. In getting out the ground the method pursued will vary so much under different circumstances that little can be said about it here. In very bad marshy ground, abounding in land-springs, and otherwise disadvantageous, it will often be found less expensive to construct an iron tank.

At Chester, Mr. Clegg found so firm and impervious a bed of red rock that no brickwork or puddling was necessary, the tank being simply fashioned with the pick, and a few land-springs stopped. The earth-work in the centre of the excavation may be left, with a sufficient slope to guard against slips, and may in some cases be wattled. These slopes will vary according to the nature of the ground; a good gravel will stand at the slope shown in the engraving; if of clay and sand mixed, it had better be removed; clay alone will stand at about $1\frac{1}{2}$ to 1. In all cases the surface of the mound must be puddled two feet thick.

In tanks whose diameter does not exceed fifty-five or sixty feet, the earth, if requiring puddle or other finishing, may be got out entirely, as it will be found cheaper to do so. In rock, the centre portion may be left in for much smaller diameters.

I have not noticed the counter-weights, or specific-gravity apparatus, as they are termed by some, because I consider them (when applied to such gas-holders as I have just attempted to explain) productive of evil rather than of good. If gas-holders are counterbalanced, while the pressure opposed to the entrance of the gas may be decreased, it is also decreased when the gas is required to flow from them, and the weights must be removed, which will be attended with labour, and often with difficulty. It will generally be found that gas-holders require weighting rather than balancing, as the pressure necessary for forcing the gas through

the street-mains usually exceeds that given by the vessel itself. In a well-constructed apparatus both pressures ought to be equal, but I only know of one or two instances where the adjustment is so correct.

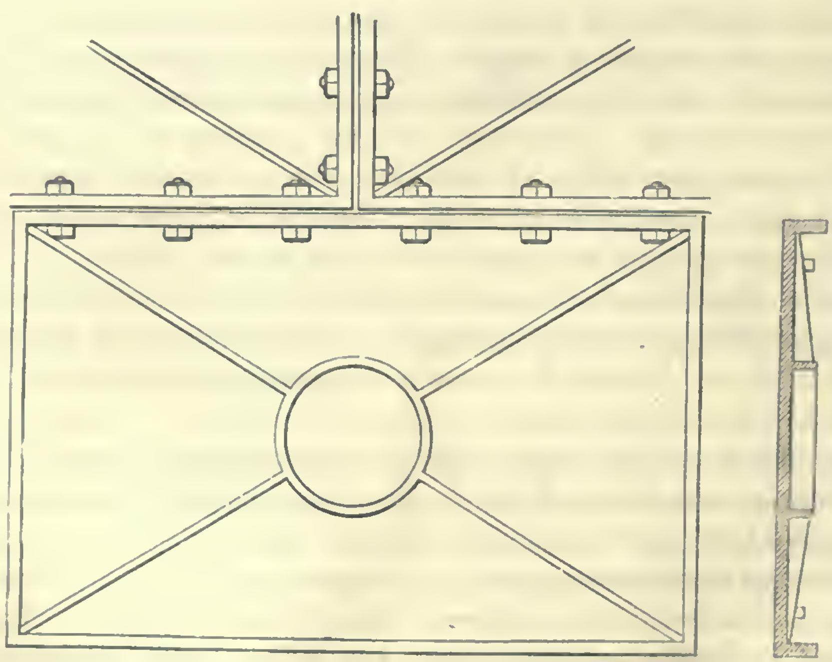
TELESCOPE GAS-HOLDER.

I now have to speak of the "Telescope Gas-holder," so called from being something similar in its action to the lengthening slides of that instrument. They are only used in cases of necessity, arising from confined space or bad ground.

The tanks of these vessels are usually formed of cast-iron, which constitutes the principal part of their expense, when compared to those of the simple form. By reference to Plate XVII., the action will be more clearly understood.

A A is a cast-iron tank, fifty-one feet diameter and twenty-five feet high, constructed of plates about three feet one inch deep, by five feet wide, strengthened by ribs, and jointed together with flanches and cement in the usual way, as shown in the annexed cut, which is drawn to a scale of three-quarters

Fig. 31.



of an inch to the foot. The figures at the side of the tank in the engraving refer to the thickness of metal at that part opposite to which they are placed.

In any vessel containing a heavy fluid, the parts that are deepest below the surface sustain a proportionally greater pressure; in the construction of the tank therefore we should run into superfluous expense by making the sides equally thick in every part; for if the substance be uniformly thick, and the lower parts are sufficiently strong, the upper parts are consequently much more so than necessary. The method suggested by theory is, while we give to the whole tank the same interior diameter, to give a safe and sufficient thickness at the lower part, and let it gradually diminish to the top, in the same ratio nearly as the diminution in the depth of the fluid. But in practice we must vary the construction; for although the plates of which the tank is composed, taken separately, may be sufficiently strong to resist the pressure of the water, yet, taken collectively, their thicknesses must depend in a great measure upon the strength required at the joints; therefore iron hoops are added to the two lower tiers of plates, to make up the difference in strength between the upper and lower tiers, instead of increasing the thickness of metal at these parts, and adding to the expense.

It may be as well also to say, that in bolting the plates together they must "break joint," as represented in the figure.

The plates forming the bottom are three-quarters of an inch thick, and joined in the same way as those at the sides.

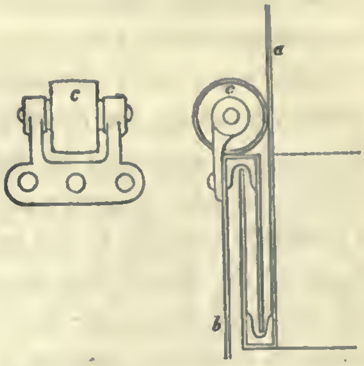
B B is the lower division or slide of the gas-holder, furnished at the upper part with a returned rim, *b*, about twelve inches deep, and three inches wide from the side.

C C is the upper division, having at its lower edge a corresponding rim at *b*, but reversed; so that when in action it has risen to its full height, the returned rim of the lower division will dip into the water contained in that of the lower one, and form an hydraulic joint.

In the action of this gas-holder it is evident that the upper portion must rise first, and having attained the proper altitude, will, as it were, unite itself with the lower portion, when they will both rise together: the whole vessel is guided by rollers, similar to those used in ordinary gas-holders; but in addition to these, it is found necessary, for the greater security of the upper portion, to use standards and balance-weights, because the perpendicular height being great, the vessel would otherwise have a tendency to work sideways, or bind; and likewise, the weight bearing a large proportion to the surface, unless some portion of it were removed by a counterbalance, the opposition to the flow of the gas into the vessel would be inconveniently great.

Figure 32 will explain the water-joint: *a* is the upper, and *b* the lower portion of the gas-holder, dipping into the water twelve inches; *c* is a roller, guiding the upper portion as it rises. These rollers may be placed about six feet apart, entirely round the vessel.

Fig. 32.



D D are the standards, cast in several lengths, bolted to the tank, and braced at the top by the girders E.

F are the balance-weights, regulated according to circumstances; that is to say, if the gas-holder, when brought into action, is found to oppose too much resistance to the entrance of the gas, weights must be added, until the pressure corresponds with that of the other gas-holders in the works, or is equal to about three inches perpendicular head of water. It is often necessary to balance both the upper and lower vessels.

The braces and ties for strengthening the sides and top of these gas-holders are precisely similar in arrangement to those in ordinary use, and need not be again described. A well for the reception of the outlet- and inlet-pipes is not of course necessary, as the tank is above the level of the ground. The receivers and valves are the same.

There is not the slightest drawback to the practical adoption of these Telescope Gas-holders; they rise and fall with the same precision, and can be adjusted with the same nicety, as the single gas-holder. The wear and tear is about the same, and are repaired with the same ease, but their first cost is greater, and therefore they are not generally used, except in cases before mentioned. They are in use at the Chartered, Phœnix, London, City, and some other companies' works in London, and are worked with the same confidence as the more simple vessels.

I insert the following extract from Mr. Clegg's Journal, because the observations contained therein are founded upon a practice of half a century, and are therefore valuable:—

"All the gasometers at the works must be connected together, as if they were one vessel, and each one must regulate its own pressure, by a wooden curb, assisted by weights where found necessary, when the gasometers are put into action. The flow of gas from one to another must not, on any account, be guided by a workman, nor must he be allowed to close any valve connected with them, unless

expressly ordered to do so. Indeed it would not be amiss to remove all the valves, and seal the outlet- and inlet-pipes by water, when the gasometer they belong to requires repair.

"I would warn all young engineers upon the necessity of making pneumatic, hydraulic, and other machinery, as much as possible *self-acting*. In the first place it is the perfection of mechanism; in the second place it prevents danger from neglect; and in the third place it is universally found cheaper, and tends much towards the economy of machinery in general.

"When the steam-engine was first invented, a boy was employed to open and shut the valves connected with the steam-ways, above and below the piston, when the engine was at the top and bottom stroke. A man was also employed to regulate the quantity of steam according to the power required. The engine now regulates itself. The damper which regulates the draught of the furnace rises and falls, as the steam is high or low, by the same contrivance as that by which the water in the boiler is kept at one uniform level.

"The water-wheel, if it does not regulate its own supply of water, according to the quantity of work it has to perform, is a very imperfect machine. The same may be said of windmills, blowing-engines, and even of switches on railways, which ought also to be self-acting; and in gas-works where it can be, and is not done, it is the cause of many serious accidents.

"In all the parts that are self-acting, such as the hydraulic main, no accident ever arises from a neglected valve, which was constantly the case when there was a valve to each retort requiring attendance. The engineer of the Glasgow gas-works, when they were first erected (and before Mr. Liddle had the management of them), would not use the hydraulic main. Had he been as ready to embrace new improvements as he was to find fault with what he would not be at the trouble to understand, we should have had a more correct account of the subject of 'Gas-Lights' in the Supplement to the Encyclopædia Britannica. In speaking of the Telescope Gas-holder, he says:—

"'Other contrivances have been proposed for saving of room, on somewhat similar plans, but, like the above, they are not deserving of much attention, and only proper to be resorted to in cases of necessity.'

"They probably will not be resorted to but in cases of necessity, because they are more expensive; but they certainly *are* deserving of attention, and gas-companies are much indebted to the inventor. No engineer who uses them will find any practical difficulty in their operation.

"Again, he says, when speaking of a gasometer without counterpoise:—

"'Fig. 5 is another variety of gasometer which appears lately to have got into use, though it is very imperfect, or rather totally deficient in the essential property of giving a uniform pressure to the gas contained within. Having no counterpoise, it requires to be elevated by the forcing in of gas under a considerable and varying pressure, and the addition of a regulator or governor is necessary to equalize that pressure where the gas is emitted for the purposes of combustion.'

"Now the above is given with an opinion so decided, that it might lead to great inconvenience, as it is totally wrong; for no one now would think of counterbalancing a gasometer to the nicety he seems to think necessary; and I should never think of using counterweights at all, except in telescope gasometers, or under circumstances described at page 214, having invariably found that they require an additional weight rather than a decrease; and as to the governor, it certainly is a much more scientific and correct machine for regulating the flow of gas into the street-mains, than an immense framing to support wheels and balance, with a chain sufficiently heavy to regulate the specific gravity of the iron of the gasometer: the former would cost about £20, and be perfectly correct without friction; the latter would cost £200, and the friction be very great.

"Engineers are not always to be blamed for the imperfections of their establishment, as they are in many cases tied down by directors, who, wishing to increase the dividend of the company, often go to extremes.

"It is certainly praiseworthy in them to do their best for the company which they represent; but if they employ an engineer, and place confidence in him, they ought to be guided, in matters involving essentially engineering questions, by his opinion. It is not to be supposed that a man, simply because he *is* a director, should know better than those who by education and constant practice are qualified to judge of the necessary arrangements in the economy of a gas establishment.

"There are many parts of the apparatus objected to because they are in the first instance expensive, and because it is possible to carry on the works without them. The directors, not being gifted with foresight, see only the present outlay, and do not consider the *constant* saving, because those savings are small. System, order, and proper attention to these small savings are the groundworks of economy, and consequently the best means by which their dividend may be increased."

WEIGHTS AND ESTIMATES OF GAS-HOLDERS.

The weight of a gas-holder of 87 feet 6 inches diameter, and 25 feet high, the sides made of No. 16 wire-gauge, and top of No. 14, will be as follows :—

	Tons.	Cwt.	Qrs.	lbs.
Sides, No. 16 wire-gauge	8	13	1	23
Top, No. 14 ditto	9	1	0	7
T-iron at the sides	6	19	2	0
Angle iron	2	10	1	24
Iron rings, clips, etc.	2	3	1	23
Cross-braces, pipe, stays, eyes, bolts, etc.	3	14	3	8
Rivets	0	7	2	5
Curb at bottom	5	0	0	0
Tons	38	10	1	6
Eight sets of tripods, each £5. 2*s*. 1*d*.	40	18	0	0
Bolts, brackets, etc.	0	9	3	8
Tons	41	7	3	8

	£.	*s.*	*d.*
Estimate for gas-holder, including the erection	1292	0	0
Tripods, etc.	317	10	0
	£1609	10	0

Estimate for Excavation and Brickwork of Tank.

	£.	*s.*	*d.*
2625 Cubic yards of excavation in stiff marl, at 1*s*. 8*d*.	218	15	0
35½ Rods of stock brickwork, in Mortar, at £13	479	5	0
590 Cubic yards of puddling, to stop land-springs, and filling in, at 1*s*. 9*d*.	51	12	6
	£749	12	6

The large gas-holder at the Pancras Station of the Imperial Company is 100 feet in diameter, and 39 feet high at the sides, containing 300,000 cubic feet. Its weight is as follows :—

	Tons.	Cwts.	Qrs.	lbs.
30 Pieces of bottom curb	6	16	1	5
8 Bags of rivets	0	9	3	10
60 Plates and rivets for bottom curb	0	1	1	4
24 Bottom eyes	0	8	0	24
100 Small sheets, 2 plates each, for side plates	2	8	0	17
300 Large ditto, 6 plates each, ditto	19	6	0	7
30 Short pieces of angle-iron bottom curb	0	3	0	0
24 Vertical stays	10	16	2	0
60 Pieces of angle-iron top curb	2	13	1	26
350 Short bracket irons for crown framing	1	9	1	17
4 Bags of rivets	0	5	0	0
1 Centre crown plate	0	9	3	17
1 Cast-iron cup and ring	0	18	2	6
1 Centre pipe	0	10	0	23
6 Bags of rivets	0	9	3	2
1 ditto ¾-bolts	0	3	3	6
150 1-inch bolts for top curb	0	5	0	1
50 Upright rods	2	11	3	19
50 Ditto ditto, 6 feet long	1	2	2	0
50 Ditto ditto, 3 feet 6 inches long	0	9	0	7
150 Long braces	3	4	1	9
196 Crown plates	17	5	2	15
8 Diagonal stays at centre pipe	0	2	2	8
48 Small plates at bottom and top curb	0	4	0	4
1 Man-hole, cover, ring, and bolts	0	0	1	24
130 Small plates for joints and bolts	0	3	0	15
100 1-inch bolts, and 100 ¾ ditto	0	3	2	8
100 ⅝-bolts	0	0	2	4
50 Principal bars for roof	11	17	1	23
50 Secondary bars	3	16	2	2
50 Tie-rods for principal	4	17	3	2
1 Bag of bolts	0	1	0	17
200 Diagonal stays for roof	1	11	3	26
72 Cast-iron brackets for vertical stays	0	15	2	16
24 Timbers for middle, curb, and king-post	1	0	2	8
48 Tie-rods and bolts for ditto	0	12	0	24
12 Cast-iron carriages, rollers and bolts, complete	2	6	2	0
4 pigs of lead for ditto	0	3	0	0
2 Extra man-holes, plates and rings, over 18-inch pipes	0	0	3	16
Tons	100	6	3	17

	Tons.	Cwts.	Qrs.	lbs.
24 Brackets for guide-rods	2	2	0	16
24 Lock-nuts for bottom of guide-rods	0	5	0	16
24 Guide-rods, each 6, 3, 20	9	3	0	8
12 Sets of tripods, each 8, 13, 3, 1	104	5	0	12
528 1-inch bolts for ditto	0	18	3	12
Tons	116	14	1	8

The following is the weight of a gas-holder 50 feet diameter and 18 feet deep, containing 35,300 cubic feet. Top, No. 14 wire-gauge; sides, No. 15 ditto:—

	Tons.	Cwts.	Qrs.	lbs.
Iron-work of gas-holder	10	14	2	27
Wood-curb and diagonal stays, bolts, etc.	1	19	0	0
Sundry bolts, man-hole, etc.	0	5	0	0
Tons	12	18	2	27
5 Sets of tripods	10	6	1	17
5 Guide-rods	1	0	1	12
Tons	11	6	3	1

Estimate.

	£.	s.	d.
Gas-holder work, including erection	456	2	0
Cast-iron work, at £7. 10*s*. per ton	85	0	0
	£541	2	0

Tank for the above.

	£.	s.	d.
1890 Cubic yards of excavation, at 10*d*.	78	15	0
176 Cubic yards of puddling at bottom, at 1*s*. 6*d*.	13	4	0
334 Superficial feet of York landing at bottom of wall, at 1*s*. 9*d*.	29	4	6
12½ Rods of stock brickwork in mortar, at £13	162	10	0
238 Cubic yards of puddling, and filling in behind wall of tank, at 1*s*. 6*d*.	17	17	0
70 Cubic feet of Bramley Fall stone for tripods, at 4*s*. 3*d*.	14	17	6
	£316	8	0

A gas-holder 36 feet diameter and 12 feet deep contains 12,200 cubic feet, and weighs as follows:—

	Tons.	Cwts.	Qrs.	lbs.
Ironwork of gas-holder, sides of No. 18 and top of No. 17, wire-gauge	2	17	2	1
Wood-curb and diagonals	1	0	3	13
Stays and bolts	2	5	0	7
Sundry bolts, man-hole, etc.	0	2	1	0
Tons	6	5	2	21
3 Sets of tripods	4	19	1	0
3 Guide-rods	0	3	0	21
Tons	5	2	1	21

Estimate.

	£.	*s.*	*d.*
Gas-holder work, including erection	210	0	0
Cast-iron work at £7. 10*s.* ditto	37	10	0
	£247	10	0

Tank for the above.

	£.	*s.*	*d.*
752⅔ Cubic yards of excavation, at 1*s.*	37	12	8
107 Cubic yards of puddling at the bottom of tank, at 1*s.* 6*d.*	8	0	6
246 Superficial feet of York flagging under wall, at 1*s.* 9*d.*	21	10	6
5½ Rods of brickwork in mortar, at £12. 10*s.*	68	15	0
119 Cubic yards of puddling, and filling in behind wall, at 1*s.* 6*d.*	8	18	6
30 Cubic feet of Bramley Fall stone for base of tripods, at 4*s.* 3*d.*	6	7	6
374 Cubic yards of earth carted away, at 2*s.* 2*d.*	37	1	10
	£188	6	6

I have given the above estimates of gas-holders that have been executed, to serve as some guide to the knowledge of the cost of that part of the apparatus. The prices of the ironwork will vary with the market; other materials will also

vary at different places. I once received estimates from two houses for a gas-holder fifty feet diameter and eighteen feet deep, to be delivered in London in convenient sheets for shipment; one price was £250, the other £176. The following tenders for a gas-holder sixty feet diameter and sixteen feet deep, with a cast-iron tank, were sent in to a provincial gas company in 1850.

	Tank.	Gas-holder.
C. G.	£1060	£500
H. & M. G.	1033	439
K. & C.	950	...
W. & W.	947	463
B. G.	895	...
M. K.	845	415
G. D.	800	425

The tenders accepted were those of B. G. for the tank (£895), and W. & W. for the gas-holder (£463). It is requisite therefore, before deciding, to examine into the merits of the contractors as workmen, and also to determine the precise *meaning* of their tenders. The fairest way of arriving at a decision in the acceptance of a tender, is to make your own estimate carefully, and accept that which is nearest to it. This however is not always judicious, because a contractor may be sometimes enabled to send in a very low price, from having convenient materials by him, and for reasons of trade.

It is hardly necessary to observe, that the cost of brick-tanks will never be twice alike. If the ground in which the tank of the gas-holder represented in the engraving was built, had been less favourable, the thickness of the retaining wall must have been greatly increased, and other expenses incurred, perhaps amounting to one-half more than the estimate given here.

The estimates for the tanks of the two last gas-holders will seldom be exceeded, as they were built in ground requiring strong rivetments.

If the ground in which the tank has to be built is examined by a *practical* man, the cost can be estimated to within almost a few shillings.

The "working pressure" of a gas-holder will depend upon the area of water-surface, and the weight of the vessel itself. For example, in the one quoted as 100 feet diameter, the area of water-surface is 7854 feet, a stratum of which $5\frac{5}{10}$ inches deep will be equal in weight to the vessel, viz. 100 tons 5 cwt. Its working-pressure will therefore be equal to a column of water $5\frac{5}{10}$ inches high.

The working-pressure of the gas-holder 87 feet 6 inches diameter, weighing 38

tons 10 cwt., will be found equal to a column of water $2\frac{7}{10}$ high, the area of the water-surface being 6013·2 feet.

A gas-holder 50 feet diameter, weighing 12 tons 18 cwt., will rise with a pressure of $2\frac{8}{10}$ inches perpendicular head of water, and a gas-holder 36 feet diameter, weighing 6 tons 5 cwt., will work with a pressure equal to a head of water $2\frac{7}{10}$ inches high.

The weight of a cubic foot of river-water is 62·5 pounds.

The pressure or head of water in inches, required to raise any gas-holder, is found from the simple formula $h = \frac{w}{a\,5{\cdot}2}$; where w is the weight of the gas-holder in pounds, a the area of the water surface, and 5·2 a constant, being the weight in pounds of a square foot of water one inch deep.

To find the weight of a gas-holder, the working pressure being given, the equation becomes $w = a\,5{\cdot}2\,h$.

THE GOVERNOR.

THE Governor is a machine for regulating and equalizing the flow of gas from the gas-holders to the street-mains, and is much more perfect in its action than any slide-valve applied for that purpose requiring attendance. Its use is nowhere sufficiently appreciated. Had it been a complicated piece of machinery, or expensive in its first cost and after application, objections to its adoption would not have been surprising; but it is perfectly simple: its action is certain and unvarying, and its first cost inconsiderable.

The velocity of gas in the mains and pipes of supply is, in the first instance, as various as there are differences in their altitudes and extent. A main at one place will furnish, with a certain pressure of gas, a flame one inch high, while at a different altitude it will furnish a flame double that height. If, again, in the direction of the main there are many bends, angles, or contractions in its diameter, the velocity of the gas through it will vary considerably more than if it were direct and uniform. If the pipe be of any great length and of a uniform bore, but unequally furnished with branches, the burners will be unequally supplied with gas; those which are near its head will be supplied with a fuller stream of gas than those which are situated towards its termination.

Independently of these differences, arising from diversity of local positions, there will always be one great variation in the velocity of the gas, occasioned by the variety of periods during which lights are required by different consumers supplied from the same main or system of pipes: for example, when a certain number of burners are to be supplied, and it happens that one-half are shut off sooner than the rest, the velocity of the gas in the mains will be materially increased, and the remaining lamps must be turned down; but many would not be reduced, unless the gas were burnt by meter, and the Company would lose much; in the street or public lamps the loss is always considerable, even presuming the utmost care at the works.

The inequality thus occasioned may be seen particularly exemplified in the case of houses situated in the vicinity of any large manufactories, and supplied with

gas from the same mains. While the establishments are open, the lights in the adjacent houses are low and feeble, often too much so for the necessary purposes of the consumer; but the moment the manufactories are closed, the great quantity of gas which they previously carried off being transferred to such of the shops or private houses as continue to be lighted, their flames are raised to an extravagant height, and burn with the formation of large quantities of smoke, from the imperfect combustion of the gas. The remedy for all these evils, resulting from the various degrees of velocity of gas through the mains, is to be found in the governor.

It is true, that at a certain time during the evening, when a number of lights ought to have been turned off, the slide-valve at the entrance of the main on the works may be partially closed by the attendant, but this never effects the object properly; whereas the governor, besides being self-acting, regulates the supply exactly according to the demand. This is especially valuable where meters are used.

For the purpose of lighting all ordinary districts, one leading main from the works is sufficient, and therefore one governor. If it be necessary to have more than one leading main, a separate governor must be used to each.

Lisbon is an example of a town that would require not less than three separate pipes of supply, because its elevations are great, and rise suddenly in terraces, one above the other; but there are few towns that would present such difficult sections; still, without considering the number of leading mains, I should use governors to them all.

In Plate XVIII. will be found an elevation, in section, and a plan of a governor capable of equalizing the flow of 300,000 cubic feet of gas in twenty-four hours.

A A is a cast-iron tank containing water, five feet four inches diameter, and four feet six inches deep, in which the regulating vessel B B floats.

C is a cone of cast iron, turned true in the lathe, and suspended by an eye-bolt to the top of the floating vessel.

D is the inlet-pipe, having a plate *d* on the top, furnished with an aperture, bored out to fit the diameter of the cone at the base, and which, if raised to that height, will completely shut off the gas from entering the vessel.

E is the outlet-pipe, its diameter being regulated by the distance to which it has to convey the gas to the equilibrium-cylinder of the street-mains.

The floating vessel B, when immersed in water, of course loses a portion of its weight, equal to that of the water which it displaces; and the density of gas con-

tained in it will vary as the immersion. By making the chain F of a proper weight it may be made to answer the purpose of a regulator of the pressure. Let it be supposed, for example, that the vessel weighs 1000 lbs., and 100 lbs. of that weight when immersed in the water, and that a portion of the chain, equal in length to the height which the vessel rises, shall weigh 50 lbs., and the counterbalance weigh 950 lbs.

	lbs.
Then, when the vessel is immersed, its effective weight is . . .	900
To which must be added the portion of chain now acting, as increasing the weight of the vessel	50
The sum corresponds with the actual weight of the counterbalance .	950
Again, let the vessel be elevated out of the water, its actual and effective weight then is	1000
To balance which is opposed the counterpoise	950
And the portion of the chain now removed to the other side of the pulley to counterpoise, and acting with it	50
The sum corresponds with the actual weight of the vessel . . .	1000

The effects of the vessel and counterpoise being thus opposed to each other, the pressure of the gas contained therein is equalized.

By adding to or removing the weight of the counterbalance, an increase or decrease of pressure may be effected.

The action of the Governor is as follows. The outlet-pipe is connected with the mains, and the inlet-pipe with the gas-holder supplying gas into the machine: it will be evident, that if the density of the gas in the inlet-pipe becomes by any means increased, a greater quantity of gas must pass between the sides of the adjusting cone, and the aperture in the plate *d*, the consequence of which will be that the floating vessel will rise, and therefore contract the area of the opening in *d;* and if, on the contrary, the gas in the inlet-pipe decreases in density, the vessel will descend; so that whatever density the gas may at any time assume in the gas-holders or mains, its pressure in the floating vessel will remain uniform, and consequently the velocity of the gas passing into the mains will be regular: for when the aperture of the plate *d* would admit more gas than necessary for the supply to the mains, the floating vessel rises and diminishes the area of the

inlet-pipe; and when, on the contrary, the inlet-pipe does not allow a sufficient quantity of gas to come from the gas-holder, the gas passes out of the governor into the mains, and in so doing the vessel descends, and increases the area of the inlet-pipe, to admit the requisite gas into them.

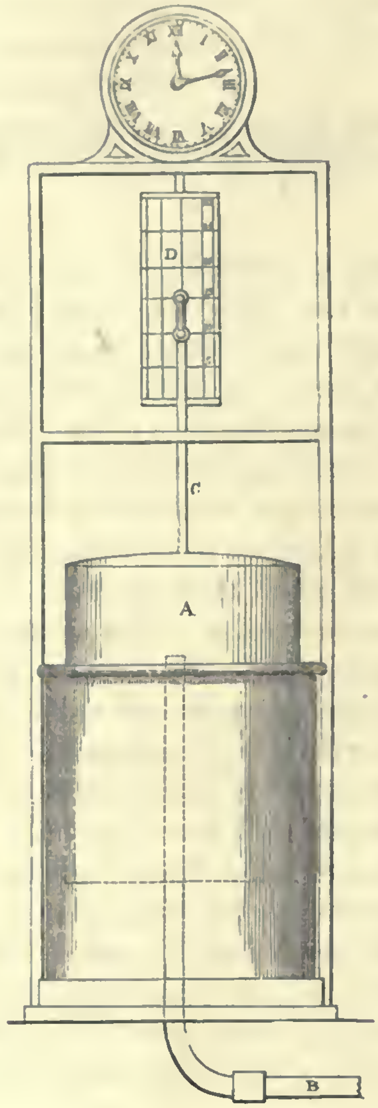
This action is not influenced by any circumstances connected with pressure or velocity, but is constant and uniform, ensuring at all times a proper and sufficient discharge.

PRESSURE INDICATOR.

If a governor be not used, it is advisable to have a *Pressure Indicator* attached to the main or mains that leave the works, to serve as a check upon the conduct of the workmen, whose duty it is to regulate the pressure of gas in them according to the demand at certain hours of the night. It is, in fact, an instrument giving the same information to the superintendent as the "tell-tale" of the station-meter. It is thus constructed: a small gas-holder about twelve inches diameter is made to move in a tank of water in such a manner that it shall rise or fall according to the pressure in the mains, with which it is connected by a small pipe; a guide-rod, furnished on the top with a pencil, marks the exact amount of pressure upon a sheet of paper coiled round a cylinder. This cylinder is moved round once in twelve hours by a timepiece. It is evident therefore that if the paper be divided by horizontal lines corresponding to the rise or fall of the gas-holder by every tenth of an inch increase or decrease of prèssure, and if it be divided by vertical lines corresponding to the revolutions of the timepiece in twelve hours, it will effect the object required. The gas-holder must be formed with an air-vessel inside, so that when it is totally immersed it shall be in exact equilibrium with the external atmosphere, and when risen to its full height it shall have a pressure equal to that required to force the gas through the mains; say the height to which the gas-holder rises is equal to ten inches and the pressure required is three inches; then if the paper be divided into thirty parts by horizontal lines, each division will indicate one-tenth of an inch. Fig. 33 represents an elevation of one of these instruments.

A is the gas-holder, having double sides, as shown by the dotted lines, which serves as an air-vessel to render the gas-holder exactly in equilibrium with the external air, when totally immersed in the water. No specific gravity apparatus being attached, it is evident that every different point of immersion will require a different pressure to cause it to rise, and these being known, a correct register is obtained.

Fig. 33.



B is the pipe forming the communication between the floating vessel and the main on the *outside* of the valve, by which the opening is regulated.

C is the rod, on the top of which the pencil is fixed.

D is the revolving cylinder, divided into horizontal lines corresponding to five-tenths of an inch, and into vertical lines corresponding to the revolutions of the timepiece.

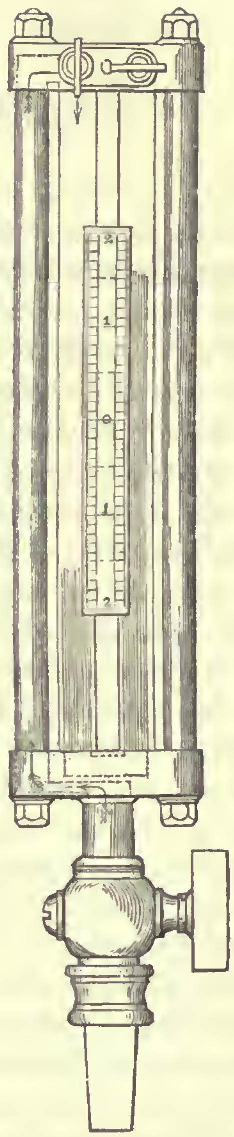
This instrument was invented by Mr. S. Crosley in 1824, and first applied by Mr. G. Lowe at the works of the Chartered Gas Company.

Pressure-gauges, as the name implies, are instruments by which the velocity with which the gas flows into the mains is ascertained. They are made of glass tubes partially filled with coloured water, and furnished with graduated scales divided into inches and tenths from a point in the centre of the scale marked zero.

When no gas is passing into the main to which one of these instruments is attached, the columns of water contained in the tubes are in equilibrium with the external air, and stand at 0. When the gas is admitted, the equilibrium is destroyed; the gas depresses one column and raises the other, the total variation being the amount of pressure. In Fig. 34 I have given a form of gauge which has a very neat appearance; the glass tubes can be taken out and cleaned, which it is difficult to do when the two tubes are connected by a simple bend. The pressure marked in the drawing is thirty tenths, or three inches; each column varying fifteen tenths from the zero-point.

The length of the tubes and the graduated scale will of course depend upon the quantity of pressure desired to be indicated.

Fig. 34.



EQUILIBRIUM OF FLUIDS.

Although the actions of various machines already spoken of depend in a great measure upon the laws of hydrostatics and pneumatics, they may be perfectly well understood, without particular reference being made to the theory of the equilibrium and motion of elastic and non-elastic fluids, and without having recourse to the various formulæ by which their effects are calculated.

For instance, in describing the action of a gasometer, it would be only necessary, in a practical point of view, to know that the pressure of the gas upon the surface of the water contained in the tank displaces a column of that water equal to the weight or gravity of the vessel, and causes it to float upwards until the gas ceases to enter, and which, if both ingress and exit are prevented, will remain at the height it has attained as long as the temperature remains the same. The action of all such vessels will depend upon the following laws:—

1. The upper surface of any fluid in any vessel, or in a number of communicating vessels, is horizontal.

2. Pressure is distributed equally in all directions, and acts perpendicularly upon every point of the surface of the vessel which contains that fluid.

3. The pressure of a fluid on the horizontal base of a vessel in which it is contained is as the base and perpendicular altitude, whatever be the shape of the vessel which contains it.

4. When the heights of the same fluid are equal, the pressures are as the bases; when the bases are equal, the pressures are as the heights; when both heights and bases are equal, the pressures on the horizontal bottoms are equal in all, however irregular the shape and capacities of the vessels may be.

5. In different vessels containing different fluids, the pressures are as the areas of the bottoms multiplied by their depths, multiplied by their specific gravities.

6. If two fluids (not capable of mixing) are contained in a bent tube, and balance each other, their perpendicular altitudes, measured from the same horizontal plane, will be reciprocally as their specific gravities.

7.—(1.) The specific gravities of bodies are in the same proportion as their weights, when their sizes are equal.

(2.) When the weights are equal, the specific gravities are *inversely* as their sizes.

(3.) When the specific gravities are equal, their weights are *directly* as their sizes.

(4.) When neither the sizes nor the specific gravities are equal, the weights of bodies are as their sizes and specific gravities together.

8. A solid immersed in a fluid, will sink if its specific gravity be greater than that of the fluid; if less, it will float on the surface.

9. The entire weight of a body which will float in a fluid, is equal to the weight of as much of the fluid as the immersed part of the body displaces.

Therefore, as the size of the whole body is to the size of the part immersed, so is the specific gravity of the fluid, to the specific gravity of the body.

I have previously described the operation of computing the specific gravity of a gas; I shall now point out the methods to be pursued in finding the specific gravities of liquid and solid bodies, which it may frequently be useful to know.

When the body is heavier than water (which is taken here as the standard of comparison, as air in the case of a gaseous fluid), weigh it both in water and out of water, and the difference of these weights will express the weight lost in water. Then, if its weight is five out of the water, and when immersed three, the weight lost will be two. The rule will be,—

As 2, the weight lost in water, is to 5, the absolute weight, so is 1·0, the specific gravity of water, to 2·5, the specific gravity of the body.

When the body is lighter than water, attach to it a piece of another body heavier than water, so that they may sink together. Weigh the heavier body and the compound body separately, both out of the water and in it, and find how much each loses in water, but subtracting its weight in water from its weight in air, and subtract the less of these remainders from the greater. Then use this proportion:—

As the last remainder is to the weight of the light body in air, so is the specific gravity of water, to the specific gravity of the body.

Suppose the heavy body to weigh seven out of water and three in water, its loss will be four; and suppose the light body weighs ·65 out, and ·27 in the water, its loss will be ·38; by subtracting ·38 from 3·00, we have 2·62.

Therefore, as 2·62, the last remainder, is to ·65, the weight of light body in air, so is 1·00, the specific gravity of water, to ·24, the specific gravity of the body.

When the specific gravity of a fluid is required, take a piece of some substance of known specific gravity, weigh it both in and out of the fluid, and find the loss of weight by taking the difference of these two; then say,

As the whole or absolute weight, is to the loss of weight, so is the specific gravity of the solid, to the specific gravity of the fluid.

Take 2·31 as the specific gravity of the known substance, suppose its weight out of the fluid to be five, and in the fluid 3·2, the loss will be 1·8.

Therefore, as 5, the whole weight, is to 1·8, the loss, so is 2·31, the known specific gravity, to ·83, the required specific gravity of the fluid.

VALVES.

I HAVE already, at page 191, given a description of one hydraulic valve: two different valves are represented in the adjoining figures. The advantages of water-valves are cheapness, durability and certainty of action. Fig. 35 shows a section of one of these valves: it is formed of an air-tight cylinder A A, containing a portion of tar or water. B is the inlet-pipe, which communicates with the gasometer; C is the outlet-pipe, which conveys the gas to the mains; D D is an inverted cup, ten inches deep, furnished with a rod passing through a stuffing-box, by which it is raised or lowered. When the cup is in the situation shown in the figure, it is evident that the communication between the outlet- and inlet-pipes is shut off by the pressure of a column of water ten inches high. When the cup is raised above the mouth of the outlet-pipe by the rack and pinion, a free passage is left for the gas. This description of valve may be fixed with advantage between the gas-holders and the mains, or between any system of lime-water purifiers Care is necessary that the cup should be sufficiently deep for the required pressure.

Fig. 35.

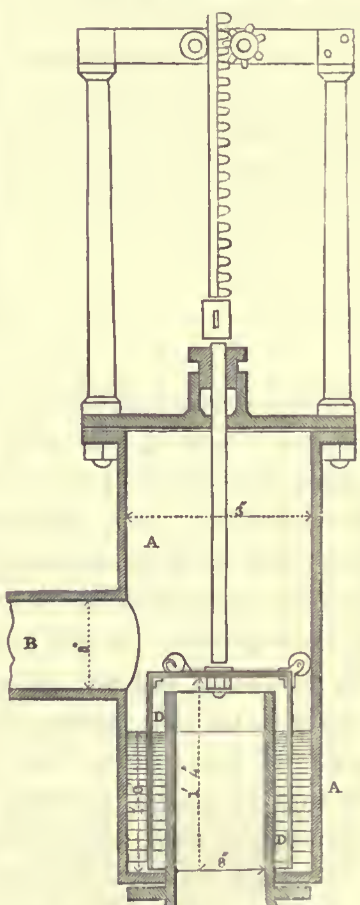
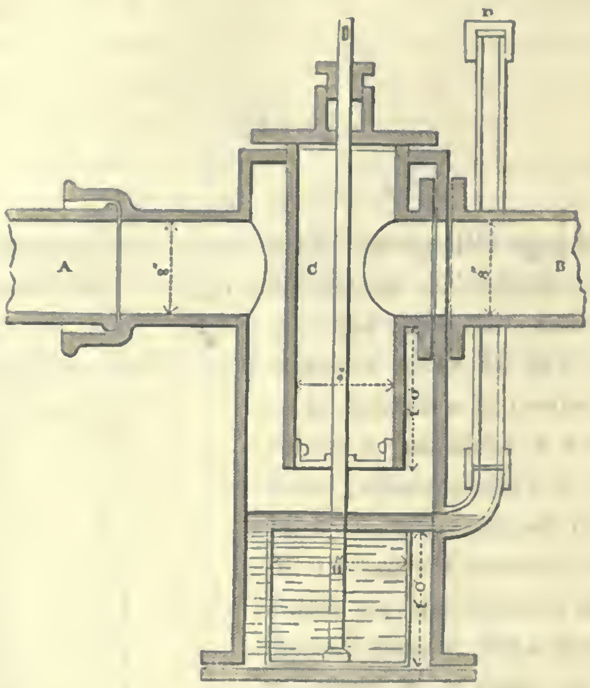


Fig. 36 exhibits a similar valve, differing only in its construction, the outer case serving for a receiver. A is the inlet-pipe; B the outlet, jointed to the side of the outer

Fig. 36.



cylinder, and communicating to the interior pipe C, which is open at the bottom, its top flanch forming the cover to the outer cylinder. The cup is brought into action by being lifted and immersing the open end of the pipe C into the tar which it contains. It will be observed, that when it is lowered, the tar contained in the receiver, being higher than the edge of the cup, will run into it and fill up the quantity displaced by C. D is a small service-pipe, through which, by a hand-pump, the superfluous tar may be drawn off.

This last form of hydraulic valve may be used in the streets, and the cup raised by a screw on the rod, working through a nut at the bottom of the cup, which, being secured from turning round, would follow the thread of the screw. As receivers must be attached at certain distances along the lengths of the main pipe to drain them of water (and a certain portion of tar and oil which still may remain in the gas even after it has travelled miles), they may be easily formed into valves, and thus be made to answer two purposes. A slide-valve is shown in Plate XIX.

Fig. 1 is an elevation, and Fig. 2 a plan at the top of the stuffing-box. Fig. 3

is a vertical section, Fig. 4 a plan in section, and Fig. 5 a back elevation of a valve.

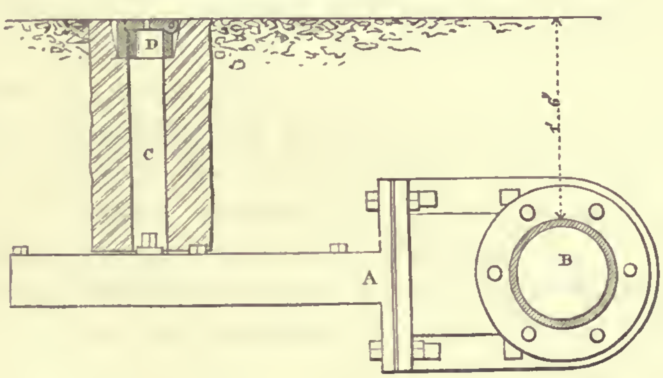
A is a faced cast-iron disc, which by being raised or depressed opens or shuts off the passage for the gas; it is pressed by the spring B against the part C of the valve-box, which is also faced.

By the rack and pinion, the disc is drawn up into the position shown by the dotted lines, the spring still causing it to work *fair* upon the faced part C.

D is a rod passing through a stuffing-box, and secured by a screw-bolt between the cross feathers cast on the back of the disc A: the same bolt fastens the spring.

The pillars and cross-head which support the pinion are only used in the works. The arrangement for use in the street-mains is represented by Figs. 6 and 7. The rack and pinion is here enclosed within a cast-iron box, the cover being secured by four or five half-inch pins, tapped into the sides, and having a hole left for the spindle of the pinion to project through; by this contrivance no dirt can get to the teeth or to the stuffing-box. The position of the valve is explained by reference to the woodcut, Fig. 37.

Fig. 37.



A is the valve laid flat; B a section of the main; C a bored wooden block, through which the key is passed when the valve requires to be shut or opened; D is a cast-iron plug, closed at the top by a hinged lid, and driven firmly into the wooden block.

If no valve happens to be contiguous to the spot where a main should require repairing, a simple and efficacious contrivance of Mr. G. Lowe may be had re-

course to as a substitute. For example, supposing that a fractured pipe had to be taken out from the middle of a long run of main, or a junction had to be made with another; drill a hole about $1\frac{1}{2}$ inch in diameter upon the top of the pipe, on each side of the space to be taken up; through these holes insert empty bladders furnished with small tubes and stop-cocks; when these bladders are inflated, by blowing into them through the tubes, they will fill up the mains and stop the exit of the gas almost perfectly, and form an excellent temporary valve. When the repair is finished, withdraw the bladder, and stop up the drilled hole either by screwing a pin, or driving a wooden plug into it.

STREET-MAINS.

THE term Main is applied to all cast-iron conduit-pipes that serve to convey gas from the works to the place or district to be lighted, and especially applied to those pipes from which smaller ramifications branch.

Before any main-pipes are suffered to be laid, every length must be *proved;* that is, water must be forced into them until the internal pressure is equal to a column of water 250 or 300 feet high. A faulty pipe is generally at once discovered by the water issuing from it in proportion to the extent of the fracture; sometimes however the fault is only indicated by a slight line of external moisture, showing either a crack or defect at that part; if when the pressure be increased this moisture does not extend, the pipe may perhaps be retained, since such a fissure would not cause a leak, but if the crack opens under pressure, the pipe must be rejected; for although a minute fissure may at first be gas-tight, yet after being exposed under the ground to wet and frost, it would soon increase and become leaky.

In warm weather, if the pipe be proved with *cold* water, a dew-point will be formed, which, by condensing the vapour in the atmosphere upon the outside of the pipe, will often deceive the workmen, and lead to the rejection of those that are sound. It is therefore necessary during the summer months to prove pipes with water of the same temperature as the atmosphere.

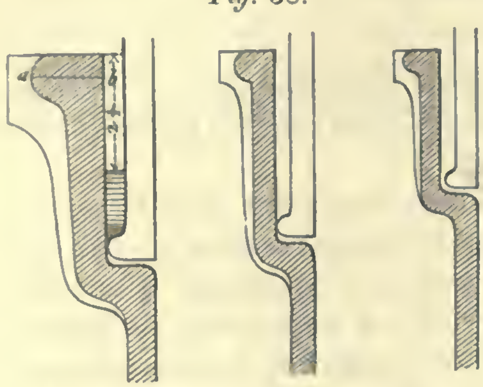
An experienced workman in the habit of proving pipes will distinguish a perfect pipe from a faulty one with considerable correctness, by the difference in sound produced by blows of a hammer. A perfect pipe will ring when struck, while that having a crack will jar; by this means also a difference in the thickness of the metal may be detected*. The proving machine however should always be used, and with care, for every leak is so much constant loss of gas, and of money to the manufacturer.

* It should be specified that the pipes be cast in an upright position, unequal metal being then less likely to occur, and the density will be greater.

Sockets.

Nos. 1, 2, and 3, in the adjoining figures, represent the sections of sockets of different-sized pipes to a scale of three inches to one foot. No. 1 is that of mains from nine to twenty-four inches diameter. The usual thickness of metal is shown by the hatched lines, and is proved to be sufficient; the pipes are occasionally made of the thickness marked by the outside line; the reason given being that "thinner metal cracks in making the joints." This is an erroneous idea, since the extra strength must depend on the width of the bead from *a* to *b*. The *depth* of these sockets is 4½ inches.

Fig. 38.



No. 2 is a section of the sockets of mains from four to eight inches diameter; their depth four inches.

No. 3 is the thickness of those of a smaller diameter, three inches deep.

The throat of the socket a little stronger, as shown in Fig. 38.

The weights and dimensions of the ordinary gas-mains are as follow:—

Diameter of pipe in inches.	Length.	Thickness.	Weight per length.			Cost per yard.		Price per ton.		
	Feet.	*Inch.*	*Cwts.*	*Qrs.*	*lbs.*	*s.*	*d.*	*£.*	*s.*	*d.*
2	6	¼	0	1	14	1	3	6	10	0
3	6	¼ full	0	3	14	2	0	6	10	0
4	9	⅜	1	1	14	3	1	6	10	0
5	9	⅜	1	3	0	4	2	6	10	0
6	9	⅜ full	2	1	14	5	4	6	10	0
7	9	½	3	0	7	6	2	6	0	0
8	9	½	3	2	7	7	4	6	0	0
9	9	½	4	0	7	8	6	6	0	0
10	9	½	4	1	14	10	1	6	0	0
12	9	½ full	6	2	0	13	4	6	0	0
14	9	⅝	7	3	0	16	1	6	0	0
16	9	⅝ full	9	2	14	19	9	6	0	0
18	9	¾	11	0	0	22	10	6	0	0
20	9	¾	13	1	0	27	0	6	0	0
24	9	¾ full	16	2	0	34	3	6	0	0

The annular space left between the bead of one and the socket of the next pipe, should be about half an inch in the large mains, and not less than three-eighths in the small. The diameters of the sockets must therefore be guided by this.

The cost per yard of pipe at the price of £6. 10*s.* and £6 per ton is added to the above table, as it may be sometimes found convenient for reference, but it cannot of course be a constant guide, since the price of iron is for ever varying. Elbows, bends, and particular castings are charged extra, except in large contracts, where a special agreement may be made.

Pipe-laying.

The gas manufacturer strives his utmost to save in his production account, and is sometimes well content if the cost per thousand is lessened by one penny. This ambitious economy is very praiseworthy, without doubt; but in nine cases out of ten these efforts are neutralized by the amazing quantity of gas which escapes from the street-mains; fortunate is he whose loss is less than 15 per cent., for many lose 20, and some as much as 25 per cent. The waste arises from one or all of the following three causes:—First, the pipes themselves may be faulty, and be put into the ground without having gone through the ordeal of the proving machine. Secondly, they may be laid and jointed by contract, without so strict a supervision as such an operation demands; the consequences have often been, that the joints have little lead in them, sometimes none, and such things have happened as the ends of pipes left entirely open: such violent leaks are, it is true, soon discovered, but yet many of the others remain. The third cause of leakage is often attributable to the hurried manner in which the Gas Companies are obliged to complete their work, and even if they lay the mains with their own hands, cannot prove them, or watch them; the trench is covered in, the paving made good, and the inspector prevented from seeing that all was right, from sheer hurry to complete the operations.

The price for laying pipes varies considerably, and will depend upon the nature of the ground, upon the kind of road-surface, upon the depth of the trench, the number of junctions and services, and other minor circumstances. Of the Tables on the following page, the first gives the prices for pipes lately laid in Liverpool, the second gives the prices handed in by Mr. Croll, on his examination upon the Great Central Gas Consumers' Bill.

Main pipes.	Size.	Weight per yard.	Price per ton.	Price per yard.	Weight of lead per joint.	Cost of lead.	Carting.	Trenching.	Laying pipes in trench.	Total cost per yard.
	inches.	*lbs.*	*s. d.*	*s. d.*	*lbs. oz.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
9 feet lengths, including sockets.	24	560	170 0	42 8½	31 3	2 2	0 9	4 6	0 10	50 11½
	18	364	170 0	37 9	21 0	1 5½	0 5¾	3 0	0 7½	33 3¾
	16	312	170 0	23 4¾	18 12	1 3¾	0 5	2 8	0 6	28 3½
	14	256	170 0	19 4¾	16 8	1 1¾	0 4	2 4	0 4¾	23 0
	12	212	170 0	15 8	12 9	0 10	0 3¼	2 0	0 3½	19 1¼
	10	168	170 0	12 3	8 1	0 6¾	0 2½	1 9	0 2½	14 11¾
	8	120	170 0	9 2	6 9	0 5½	0 2	1 6	0 2	11 6
	6	82	180 0	6 5	4 12	0 4	0 1½	1 4	0 1½	8 4
	5	68	180 0	4 8¼	4 3	0 3½	0 1	1 3	0 1½	6 5¼
	4	50	180 0	3 11½	3 14	0 3¼	0 1	1 2	0 1¼	5 7
	3	35	180 0	2 11	2 11	0 2¼	0 0¾	1 0	0 1	4 3
	2	22	180 0	1 9¼	1 12	0 2¼	0 0½	0 9	0 1	2 10

Diameter.	Price of laying per yard.	Diameter.	Price of laying per yard.
	s. d.		*s. d.*
24 inches	10 6	6 inches	1 10
18 "	8 3	5 "	1 7
14 "	4 10	4 "	1 4
10 "	3 4	3 "	1 2
8 "	2 7	2 "	1 1
7 "	2 3		

Paving and repairing is taken at 1*s.* 6*d.* per yard.

After a certain length of main-pipe has been laid, and before the trench is filled in, it *must* be proved, in order to be certain that all the junctures are gas-tight. The most convenient manner of doing this is by means of a portable gas-holder, about three feet diameter, running upon a truck, filled with common air, and connected, by means of a small service, with the length of mains to be tried. This gas-holder should be made to act with a pressure at least four times greater than the pressure of gas they will afterwards have to sustain. If the mains are tight, the vessel will remain stationary; if not, it will descend in proportion to the extent of the leak. This is very seldom done, because it is attended with a little additional expense and trouble; but if an engineer wishes to increase the economy of his establishment, he will do well to insist upon every quarter of a mile being proved whilst the mains are in progress of laying. From the careless manner in which the mains are generally laid, more gas is lost than all the economy in the works can make up.

Joints.

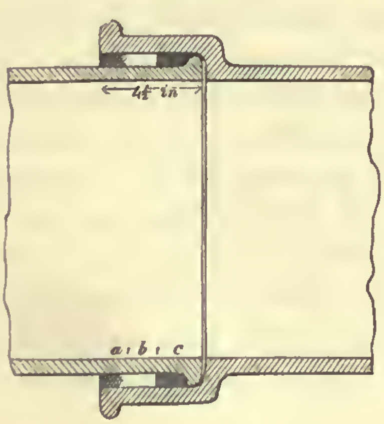
To make the joints, spun yarn is driven between the pipes to within $2\frac{1}{2}$ inches of the lip of the socket, and a good fitting of the two pipes being effected, clay is pressed round outside the end of the socket, and melted lead is poured into the remaining cavity, which, when set, is caulked or hammered in with a blunt square-pointed chisel. There is no necessity for driving the lead in very hard, as the joint will not be at all the tighter in consequence; it is very probable that the ordinary sockets before alluded to were split by downright hard-wedging; no metal will stand against such force. A strict watch must be kept over the men while jointing; they are very apt to stint the quantity of lead if the work be done by contract.

Elastic Joint.

The elastic joint for gas-pipes is very much cheaper than that of lead, and possesses other advantages.

Let the pipes be placed in the socket in precisely the same way as for a lead joint; caulk into the bottom of the socket, to the depth of about two inches, white rope-yarn well covered with putty; then at the lip of the socket caulk in tarred gaskets of such a thickness that it will just fit into the annular space left between the pipe and the socket, and to such a depth, that a space of about $1\frac{1}{2}$ inch will be left between the two yarns all round the pipe. At the top of the socket, where the ends of the tar-gaskets meet, draw up a portion to form a "gate," exactly in the same way as for running a lead-joint. Take two parts of melted Russian tallow and one part of common vegetable oil, and pour the mixture, while it is warm, into the "gate;" it will run into and fill up the space between the two yarns. As the mixture does not contract on cooling, and is quite impervious to the air, it must form an air-tight joint.

Fig. 39.



a is the tarred rope-yarn; *b* the tallow and oil; and *c* the puttied white yarn.

Half a mile of nine-inch pipe, jointed upon the above plan, has been found by the barometer to be perfectly air-tight, when exhausted, equal to a pressure of twenty-four inches of mercury.

When mains require to be taken up to be replaced by others, which is frequently the case, the pipes may be drawn out of the socket without trouble; whereas, when the joints are made with lead, the pipes are obliged to be broken before they can be removed, which causes a great sacrifice both of labour and metal.

The depth of mains below the surface of the street ought to be about one foot six inches, not less. Their course should be as nearly as possible in straight lines, inclining at the rate of 1 in 100.

In order to guard against the danger of water, and the deposition of other condensed matter, an accumulation of which would obstruct the passage of the gas through the mains, a receiver should always be placed at the lowest point, where two or more descending mains meet and form an angle. They ought to be at least twice the diameter of the mains between which they are interposed, and four times that diameter in depth. These receivers afford the best indication of the sound or leaky state of the system of mains. In instances where they are perfectly sound, observation has shown that half a mile of gas-mains, three inches in diameter, does not deposit more than a quart of condensed vapour or water in the year; on the other hand, when they are leaky, the reservoir requires to be pumped out, particularly in wet weather, as frequently as once a fortnight. The loss of gas by such leakage is much greater than is generally imagined. In order to keep the common air out of the faulty mains, a constant influx of gas is often necessary, which is a loss to the economy of the establishment.

In all wide streets, where there are a number of houses to be supplied on both sides, it is sometimes more economical to employ a separate gas-main for each side than one large main, because much smaller pipes may then be laid down, and collateral branch-pipes leading to the houses are shorter. This is simply a matter of calculation, when preparing estimates.

DISTRIBUTION OF GAS THROUGH MAINS.

When it is proposed to light any town or district of a town, with gas, the first step to be taken is to ascertain the number of lights, both public and private, that will be required, with as much accuracy as circumstances will permit; the length of time such lights will have to burn, and the quantity of gas consumed by them per hour, making allowances for the increase in the number of lamps that will probably be required by the extension of the town. The size of the works themselves may be easily ascertained from this calculation, in the manner noticed further on; it will then remain to fix upon a proper situation in which to erect them. The best local position is upon the banks of a navigable river, a canal, or a railway, *and at the lowest available level.* It is not possible to give a decided rule for the choice of situation, because the value of ground, and difficulties in many cases connected with purchase, title, etc., will throw obstacles in the way, but the advisability of so placing the works that a railway siding may be brought into them is worthy of consideration. The erection of the works upon a marshy ground will be attended with expense in foundations, but this is of minor importance to the attainment of a good situation with respect to the level. A map of the town must be obtained, or a survey made of the different streets and thoroughfares; running levels must be taken through them at several points, and their respective heights marked with reference to the level of the curb of the gasholder as a datum; upon this map all the mains must be drawn, with their branches, valves (and governors, if any are required). Their arrangement must be such as to allow of a perfect circulation of the gas, and a nearly uniform pressure throughout. All the pipes upon the same level should be joined into one another, and no valves used but such as are necessary to shut off the gas for repair of mains. To supply a higher level a governor should be placed at the summit of the lower level, with the lower main leading into it. The pipe or pipes for supplying the higher parts should proceed from this regulating vessel, and a cellar may be appropriated for its reception.

The extent of the gas-works may be estimated in the following manner:—

Let it be assumed that the number of street lamps is 1000, that they each consume 5 cubic feet per hour, and that they are lighted from sunset to sunrise; that the private burners are 7000 in number, that they also consume 5 cubic feet each per hour, and are lighted from sunset until nine o'clock p.m.

The greatest consumption of gas will of course be on or about the 21st of December, when the night is 16 h. 15 m. long, and the above number of lamps will require 261,500 cubic feet to supply them, viz. 81,250 cubic feet for the public, and 180,250 for the private lamps, and if we add to this one-sixth for leakage, we get about 305,000 cubic feet, which the works must be capable of making in twenty-four hours. A careful manager will so arrange that his retorts are all in working order at this season, all repairs and re-settings being done during the longer days; therefore the number of retorts that will make this quantity will be the total number to be erected, a few being added in case of accident, space in the house being left for future extensions. If the charge for each retort be 2 cwt. of coal, yielding 9200 cubic feet per ton, eighteen benches, of five retorts each, will be the number, which leaves one-tenth for contingencies. The gas-holder room is a consideration of moment, not generally studied; it is one not capable of being arrived at by figures, and must therefore be left entirely to the judgement of the engineer, because the probable extension of the works should govern the dimensions of the vessel, since it would cost much less in the first instance to provide one of moderately-increased dimensions, than a second one at an after period. The probable increase of the works being the principal guide, it will evidently be impossible to give any rule for the size, and attention is therefore merely drawn to the subject that it may be thought worthy of some care. The least capacity of the gas-holder for such works as are now presumed, would be that to contain 7 h. 45 m. make of gas, or say 100,000 cubic feet; but even with no expectation of increase, this would be dangerously little, and I should not hesitate to advise the contents to be made 125,000 cubic feet.

The following table will be found useful:—

Month.	Average time of sunset.		Mean duration of night.		Number of hours of night per month.		Consumption of gas by one burner per month, at 5 cubic feet per hour, street lamps assumed to be lighted from sunset to sunrise, and private burners from sunset until 9 o'clock.	
							Street lamps.	Private lamps.
	h.	*min.*	*h.*	*min.*	*h.*	*min.*	*Cubic feet.*	*Cubic feet.*
January .	4	13	15	42	486	42	2,435	742
February .	5	7	14	9	396	12	1,980	545
March. .	6	6	12	8	376	8	1,880	450
April . .	6	57	10	12	306	0	1,530	308
May . .	7	46	8	29	263	0	1,315	192
June . .	8	16	7	28	224	0	1,120	60
July . .	8	2	7	46	240	46	1,205	150
August .	7	16	9	27	292	57	1,465	270
September	6	20	11	20	340	0	1,700	400
October .	5	21	13	9	407	39	2,040	566
November	4	25	15	10	455	0	2,275	688
December.	3	49	16	12	502	12	2,510	804
Total for the year . . .					4290	36	21,455	5175

It is generally sufficient, and always advisable if possible, to have but one leading main from the works; there are however circumstances which render more first mains imperative, but the locality can alone regulate this.

The arrangements for the ramifications of the street-mains is sufficiently simple, and merely requires the exercise of a little common-sense; but the sizes of the mains must be ascertained with care, and a sound discretion exercised as to their probable future duties. Let it be always held a maxim, that a main moderately larger than necessary is economical, and for this reason, that decrease of pressure decreases leakage, which will effect a yearly money saving of more than the interest of the excess of expenditure arising from the larger main: for example, let it be supposed that 8600 cubic feet is discharged hourly, at a distance of 1000 yards from the gas-holder, through a pipe 7 inches diameter, a pressure of 1 inch of water will be requisite; and let it be supposed that the demand for gas increased, so that it became necessary to discharge 12,000, the pressure would have to be doubled. Now 1000 yards of 7-inch pipe would cost (say) £425, and the same length of 8-inch pipe (the diameter required to discharge this 12,000 feet with 1 inch pressure) would cost £500, a difference of £75; assume this to represent a yearly sum of £7. 10*s.*, and assume also the cost of gas to be 1*s.* 6*d.* per 1000 cubic feet, it would be exactly covered if the yearly saving of gas by decreased leakage were 100,000 cubic feet, or 25 feet per hour. If we take the leakage of the original 7-inch pipe to be one-tenth of the quantity passing through

2 K

it, 860 cubic feet will be the loss, but with the additional inch pressure, 1430 cubic feet would be lost upon 12,000 cubic feet, instead of 1200 cubic feet through the 8-inch pipe with 1 inch pressure, a nett loss in money of about £8 per year, so that the 8-inch main might cost £155 (instead of £75) more than the 7-inch, without disadvantage to the company.

The most convenient way of planning the supply-mains of a town is to separate it into districts, arranged that the principal streets shall as nearly as possible divide them equally; the main therefore running along such principal street will be made of a size sufficient to yield gas to the smaller pipes throughout the district. A town of any extent may thus be treated as a number of small towns, and, if a little care is taken, all confusion and almost all liability of error avoided. If imaginary lines are also drawn at right angles to the main arteries, at such distances as will most conveniently mark gradations in the quantity of gas required, the operation will be still further simplified. Thus, let the following diagram be

1	2	3	4
5000 c. feet.	4000 c. feet.	3000 c. feet.	2000 c. feet.

A B

5	6	7	8
5000 c. feet.	4000 c. feet.	2000 c. feet.	1500 c. feet.

supposed to represent a district, divided longitudinally by the street A B, and let 1, 5, 2, 6, etc., be the number of subdivisions, requiring the quantity of gas per hour marked upon them; we will also assume that the transverse lines are 300 yards apart. The main passing through the first subdivision from A will be required to discharge the quantity for the entire district, viz. 26,500 cubic feet per hour, with 1 inch pressure, its diameter will be 9 inches. The main through the second subdivision will be required to discharge 16,500 cubic feet, and its diameter will be 8 inches. That through the third subdivision must discharge 8500 cubic feet, and be 6 inches diameter. And that through the fourth subdivision 3500 cubic feet, and be 4 inches diameter. The calculation in actual practice is not perhaps quite so simple as this, because the levels, and bends, and some local obstructions may have to be taken into account, but the example will show the general principle. If towards B the town is extending, or likely to ex-

tend, and to require gas, the item in the calculation must not of course be lost sight of. The initial main from the works may be said to extend only to the first branch from it, at which point it changes its dimensions, arrived at in the manner described.

The direction in which the town will be improved or extended is generally pretty well known, therefore there can be no difficulty in arranging the discharge mains so as to meet the extra supply in that quarter. The cross pipes, whatever their diameters, should be connected together in every available place, to form a *system* of mains. On no other plan can a certain and regular pressure be ensured; deficiencies in the quantity of gas in one place will be made up by a supply from another point, in which there may be an excess, and thus cause a constant circulation. The pressure in the mains will vary directly as the rise above or the fall below the datum line, at the constant rate of one-tenth of an inch for every ten feet. Thus, at those points which rise ten feet *above* the datum the pressure will be increased one-tenth, and will be decreased one-tenth at a point ten feet *below* the datum. If therefore these points are connected together, the discharges will be in a measure equalized; and so at every intermediate elevation.

The various inconveniences arising from the scarcity of gas in some divisions, and an excess in others, are often severely felt, sometimes to such an extent that the atmospheric air will take the place of the gas, and cause what is termed a "blow." As has been before remarked, an excess of pressure causes a wasteful expenditure of gas, increases the loss by leakage, and is otherwise injurious. None of these evils will arise if the circulation through the system of mains be perfect.

If the general level of any division of the town or district rise more than thirty feet above the datum line, and be supplied from the lower level, the pressure should be equalized by a small governor, similar in construction to that at Plate XVIII. The governor need only be applied where the high level is uniform, and where there are no means of equalizing the pressure by uniting its mains with those of a sufficiently low division. Should there be two distinct portions of the town rising one above the other, like a terrace, each maintaining a general level, they will be more conveniently lighted from different leading mains, the entire arrangements being kept separate.

By these few examples I have endeavoured to convey my ideas of the most economical arrangements for street-mains. Though practical knowledge is necessary, theory will lend us considerable assistance in determining the diameters of the various mains necessary to supply the requisite quantities of gas for any length

and under any pressure. The following chapter will furnish every facility for the calculations.

I have been favoured with the following, by Mr. G. A. Jermyn, whose abilities in the surveying of towns for the purpose of distributing mains, have tended in many instances greatly to facilitate the operations in the first instance, and the regulation of the works afterwards.

"In lighting towns with coal-gas, there is no branch more worthy consideration than the arrangement of the mains, their ramifications, and the apparatus connected immediately with them, in order that every part may be in perfect keeping with the size of the magazine from which they draw their supply. To effect this, a plan of the town should be obtained; and not only is a plan giving the lengths and widths of streets necessary, but their respective levels are indispensable, for upon this latter point many circumstances will depend. Having ascertained the number of lights required in each particular street, the main must be in accordance not only as to the value of 'diameter,' but as to the density of supply likely to be obtained from its peculiar level, taking the gas-holder curb always as a datum. Errors entailing a permanent expense and inconvenience have been the result of the operations of most of the great companies, from this simple point having been neglected, and many irregularities have come under my own observation; for instance, in a street of half-a-mile in length, where one, or at the most two receivers, would have sufficed to drain the pipes, not less than twelve have been discovered when taking up the main, and this was undoubtedly in consequence of not having a proper map of reference as to where receivers had been laid down; the extra ten vessels would have covered the expense of making a map.

"Experience has made manifest how necessary it is to have a perfect record of every feature in this branch of gas-lighting, and a good plan *drawn to a large scale* is the only available method that can adopted, no *written* description will answer.

"In commencing operations for the survey, take running levels from the works with your first 'back sight' on the curb of any of the gasometer tanks, and fix upon the intersections of streets for points of reduced levels. In the margin of the map, the level and distance of these points from the works must be marked, the level in red, either above or below a line, as $\overline{5\cdot75}$ would signify a fall, $\underline{5\cdot75}$ a rise of 5·75 above the datum; the length should be marked opposite in black ink. If there is room upon the map, the level may be marked as above, within a circle on the spot.

"As the mains are laid from these points, let them be carefully plotted from the measurement-book, so that their exact position will be apparent at one view; the valves, receivers, and branches distinctly marked, and the relative positions of water-pipes, sewers, etc., occurring in the same street, that may be met with on opening the ground, or otherwise known.

"Draw the line indicating the mains of a permanent colour; ultramarine is the best, as it never fades, and is capable of being washed out in case of alterations; the plan is thus preserved distinct by avoiding erasures, which must be made if the line is marked with any but a body-colour. Show the valves by a blue cross, and receivers by a small circle at every point at which they may occur, and let the directions of their drainage be marked by arrows. If the map be to a small scale, write the name of each street within the line of buildings, and suffer no interference with the spaces, by any description but what distinctly belongs to the mains and apparatus. If any remarks are necessary, they must be written in the margin of the map, and referred to by a corresponding symbol. Show the connections; and where mains cross one another, note if under or over. It was a custom to indicate the different sizes of mains by different colours: this is a very bad method, for reasons which must be obvious; for the positive colours are few in number and are liable to fade, and even under some influences to change their colour completely. Draw the lines with ultramarine of comparative thickness, and mark the diameter with a red figure, dotting to crosses at the termination of the lengths of the respective sizes. It is also advisable that the position of the public lights should be shown, as also the district and parish boundaries. A small book should accompany each map, in which the names of the streets should be set down alphabetically, and the levels of the different points with respect to one another, and with the datum, should be distinctly noted, together with remarks on the work, impediments met with, price given for laying, etc., and all dates.

"If the town to be lighted is of two distinct levels, or has one part so much above or so much below the datum as to require to be supplied by a street-governor, such districts must be indicated in the map by a coloured boundary or contour-line (yellow, for example), and the levels of the upper or lower district, taken from their respective governors as well as from the original datum-line, and marked as before directed in the margin, distinguishing the two by letters, as D original datum, G governor, thus: $\frac{35{\cdot}27}{D}$ $\frac{2{\cdot}25}{G}$, or $\frac{D}{35{\cdot}27}$ $\frac{G}{2{\cdot}25}$. The first will signify that the point is 35·27 above the original datum, and 2·25 above the street-governor; the last, as much below.

"I have frequently been employed to construct maps, after the mains have been laid, companies having found them to be indispensable, if a correct and systematic code for the supply and repair is to be framed. The time occupied and the expense incurred in the construction of such maps will be evident, besides their necessary imperfections. Of so much importance do I consider correct maps, that I would as soon think of making a steam-engine without a drawing as lighting a town without a map."

THEORY OF THE MOTION OF GASEOUS FLUIDS IN PIPES.

THE object of the present chapter is to endeavour to elucidate the laws which govern the conveyance of fluids through pipes.

There are three ways of treating questions of this nature.

The first is that of the mere mathematician, who propounds formulæ based on theoretical views only; but, since his speculations are unaided by experience, we cannot wonder that his formulæ often prove of very little practical utility.

The second is that of the uninformed practical man, who, finding a certain result produced in some known case, will vaguely infer that therefore a certain other result ought to follow under other given conditions; but, his inferences being unguided by principle, we need not be surprised that he should often be wrong also.

The third method consists in a combination of the other two, by which the faults of each are avoided. By this course we are enabled to test and correct the deductions of theory by the results of experience, and at the same time to render our experience available by the guidance of theory. It is this method we shall endeavour to follow in the present investigation: that is, we shall in the first place explain the general principles which govern the motion of fluids through pipes, and then, by combining these with the results of experiment, show how rules may be formed for use in actual practice.

General Principles.

Let us suppose a straight horizontal pipe, of uniform section and smooth bore throughout, to be open at one end, and supplied at the other end with a fluid under pressure; and let us further, in the first instance, suppose there to be *no friction* against the sides. The fluid will then pass along the pipe and issue from its open end with a certain velocity dependent on the pressure applied. Now, the laws of mechanics teach us that this velocity is the same as a heavy body acquires

in falling from a height equal to that of such a column of the fluid in question as would produce the given pressure.

We may put this in a much clearer form algebraically.

Supposing all dimensions taken in feet, and all pressures in lbs., let $p =$ pressure under which the fluid is supplied to the pipe, in pounds per square foot.

S $=$ weight of a cubic foot of the fluid in pounds.

Then the height of a column of the fluid which would produce a pressure, p, is evidently $= \frac{p}{S}$.

Also, let $v =$ velocity of the fluid passing through and issuing from the pipe, in feet per second.

And $g =$ the force of gravity $= 32 \cdot 19$.

Then, since the velocity acquired by a body falling from a certain height is equal to the square root of the height multiplied by $\sqrt{2g}$, we have

(I.) $$v^2 = 2g\frac{p}{S}$$

which determines the velocity which will be produced by a given pressure; or,

(II.) $$p = \frac{S}{2g}v^2$$

which determines the pressure for a given velocity.

We have now to consider the retarding effect of the *friction* of the fluid along the sides of the pipe. It is immaterial whether we introduce this by estimating the reduction of velocity under a constant pressure, or the additional pressure required to give the same velocity. We shall adopt the latter plan as most convenient in calculation.

The friction of fluids upon solids depends on laws altogether different from those which regulate the friction of solids upon each other. The former have not been so well investigated as the latter, but we may consider the following principles to be sufficiently well established for our present purpose.

1. The friction of a fluid upon a solid is independent of the hydrostatic pressure to which the fluid is subjected. Thus, the friction of water passing along a pipe, under a pressure of 100 lbs. per square inch, is no greater than if the pressure were only 1 lb.
2. It is proportional to the area of the rubbing surface. Thus, the friction of water in passing along a pipe 100 feet long, will be twice as great as if the pipe were only 50 feet long; or, if the circumference of a pipe be

doubled (the length remaining the same), the friction will be doubled in like manner. If therefore l be made to represent the length of a pipe, and c its internal circumference, the friction will be proportional to $l\,c$.

3. It varies with the velocity, but in what exact ratio does not appear to be well determined. As a simple rule however, near enough for practical purposes, the friction may be assumed to vary as the *square* of the mean velocity* with which the bodies move upon each other, or as v^2. Thus, if the velocity of water passing along a pipe be doubled, the friction will be increased fourfold, and so on.
4. It may also be assumed to be proportional to the specific gravity of the fluid, or will vary as S. The friction does not appear to be dependent in any other respect upon the nature of the two substances in contact, provided only that the fluid be in a state of perfect fluidity, and that the surface of the solid be so smooth as not to offer obstructions to the passage of the fluid along it.

Combining these laws, let $f =$ the force necessary to overcome the friction caused by the passage of a fluid weighing S lbs. per cubic foot, with a velocity v, along a pipe whose length is l and circumference c. Also let M be some constant, to be hereafter determined by experiment, and which may be termed the *coefficient of friction*. Then

(III.) $$f = \mathrm{M}\,l\,c\,\mathrm{S}\,v^2$$

Now, this force must be obtained by putting an additional pressure upon the fluid in the reservoir; let $p' =$ the pressure thus added in lbs. per square foot, and let the area of the pipe $= a$. Then the total additional force which this will give, tending to produce motion along the pipe, will be $= a\,p'$. But this must be equal to f, whence

$$a\,p' = \mathrm{M}\,l\,c\,\mathrm{S}\,v^2, \text{ or}$$

(IV.) $$p' = \mathrm{M}\,l\,\frac{c}{a}\,\mathrm{S}\,v^2.$$

* The particles of fluid in a pipe move faster at the centre than at the circumference; the *mean* velocity is such a velocity as, being multiplied into the area, will give the quantity passing through. Dubuat has found that in the case of water the viscosity gives rise to an additional resistance, increasing as the simple power of the velocity, so that the friction varies as $v^2 + b\,v$, where b is a small constant. When the velocity is slow, as in rivers, etc., it is necessary to take this into account.

If now we add this pressure to that before obtained (Equation II.), we shall have the total pressure at the supply end of the pipe. Let this, expressed in lbs. per square foot = P. Then

$$P = p + p' = \frac{S}{2g} v^2 + M\, l \frac{c}{a} S\, v^2; \text{ or}$$

(V.) $$P = \left(\frac{1}{2g} + M\, l \frac{c}{a}\right) S\, v^2$$

which is the general equation for the motion of a fluid in a pipe.

If the pipe is circular, and we put d for the internal diameter, then $c - \pi\, d$ (π being $= 3{\cdot}1416$), and $a = \frac{1}{4}\, \pi\, d^2$; whence $\frac{c}{a} = \frac{4}{d}$; substituting this in the last equation, putting for g its known value, and reducing, we obtain

(VI.) $$P = S\, v^2 \left(4\, M \frac{l}{d} + {\cdot}0156\right)$$

Data furnished by Experiment.

The last expression gives the relation which ought, according to general principles, to obtain between the quantities entering into the calculation, namely, the dimensions of the pipe, the pressure, and the velocity. This must now be compared with the results of experience, in order not only to test its applicability to practical uses, but also to determine a most important element of the calculation, namely, the *coefficient of friction*, M, whose value is still unknown, and respecting which theory gives us no information.

The manner of doing this is very simple. We have only to collect several good experiments, made under varying circumstances; to insert the given quantities in Equation VI., and then to deduce from these quantities the value of the coefficient, M. If this value comes out nearly the same for each experiment, it will prove that the general equation is correct, and at the same time the value thus obtained will enable us to bring the rules into a convenient practical form.

For the present purpose we will take two experiments, namely, one on air, and one on carburetted hydrogen gas.

1. Some experiments made by M. Girard on the discharge of atmospheric air from a gas-holder at one of the hospitals at Paris, are related in D'Aubuisson's 'Hydraulique,' Art. 525. The pressure was 0·002488 metres of mercury = 6·93 lbs. per square foot; the pipe was 0·01579 metres = 0·0518 feet, in diameter; and the length varied in different experiments from about 6 to 128 metres.

At 85·06 metres long = 279 feet, the discharge was ·000409 cubic metres per second, giving a velocity of 6·86 feet per second. A cubic foot of air weighs ·0768 lbs.; therefore,

$$6{\cdot}93 = {\cdot}0768 \times (6{\cdot}86)^2 \times \left(4\ \mathrm{M}\ \frac{279}{{\cdot}0518} + {\cdot}0156\right)$$

from which we have M = ·00009.

2. By an experiment at the Chartered Gas-works, Westminster, quoted by Mr. Hawksley in the Minutes of the Institution of Civil Engineers, 1845, p. 283, it was found that under a pressure of 1 inch of water (= 5·2 lbs. per square foot) a main, 18 inches diameter and 1 mile long, delivered 66,000 cubic feet of coal-gas per hour. The gas was of the density of four-tenths that of the atmosphere, weighing ·0307 lbs. per cubic foot, and the velocity was 10·4 feet per second. Whence, according to the equation,

$$5{\cdot}2 = {\cdot}0307 \times (10{\cdot}4)^2 \times \left(4\ \mathrm{M}\ \frac{5280}{1{\cdot}5} + {\cdot}0156\right)$$

which gives M = ·00011.

It will be seen that these experiments give the value of M nearly similar in both cases; from which it may be fairly inferred that the principles upon which the formula is based are sound, and will apply in practice.

Practical Rules.

It remains now to give the rules a convenient shape for practical use.

The pressure under which gases work is generally measured by the height of an equivalent column of water, the gauges being constructed on this principle; if therefore h be made to represent the pressure in "*inches of water*," as it is termed, we have $\mathrm{P} = 62{\cdot}5\,\frac{h}{12}$, or $h = \frac{\mathrm{P}}{5{\cdot}2}$. Secondly, the density of gases is stated generally not by their weight per cubic foot, but by their specific gravity in reference to that of atmospheric air. Let s represent the specific gravity of a gas, air being 1. Then, since 1 cubic foot of air weighs ·0768 lbs., S = ·0768 s. Making these substitutions, and resolving the equation for v, we have

$$\text{(VII.)} \qquad v = 412\sqrt{\frac{h\,d}{s\,(l + 40\,d)}}$$

the dimensions of the pipe being in feet, and the velocity in feet per second.

But it will make the rule still more practical if it is altered so as to give the

quantity of gas delivered in a given time, instead of the velocity, and also to put the dimensions of the pipe in the terms usually employed, namely, the length in yards, and the diameter in inches. Let therefore

Q = Quantity of gas passing per hour, in cubic feet.
l = length of pipe, in yards.
d = diameter of pipe, in inches.
h = pressure in inches of water.
s = specific gravity of gas, that of atmospheric air being 1.

Then, after making all the necessary reductions,

$$\text{(VIII.)} \qquad Q = 1350 \times d^2 \sqrt{\frac{h\,d}{s\,(l + d)}}$$

Or, if the length of the pipe be above 400 or 500 times its diameter, or in any case if the pressure be measured in the pipe instead of in the gas-holder,

$$\text{(IX.)} \qquad Q = 1350\, d^2 \sqrt{\frac{h\,d}{s\,l}}$$

Variation in the Position of the Pipe.

At the commencement of the investigation it was assumed that the pipe was perfectly horizontal; but, as this is not generally the case in practice, it is necessary to inquire what will be the effect of variations in its position.

The key to this will be found in the first general principle above enunciated in regard to friction; viz. that the friction is independent of the hydrostatic pressure to which the fluid is subjected. From this it necessarily follows that whatever position the pipe is made to assume, provided the other elements of the calculation remain the same, the friction will be the same also.

For example, suppose a water-pipe leading from a reservoir descends to a considerable depth, and then rises again, the friction on the lower portions of the pipe will be no greater, length for length, than upon the higher ones, although in those parts the hydrostatic pressure will be, of course, much increased; and the friction of the whole pipe (setting aside for the present the obstructions caused by bends) will be no more than if it were expanded into one straight line between its two ends. Similarly, whether a pipe of a certain length be horizontal, vertical, or inclined, makes no difference whatever in the amount of friction.

It is necessary however to observe, that when the two ends of the pipe are not at the same level, and the fluid passing through it is either heavier or lighter than

atmospheric air, care must be taken to allow for this difference of level in estimating the motive pressure. For example, suppose a water-pipe, leading out of a reservoir at a point 10 feet below its surface, to descend 15 feet before it discharges: here the effective head of water tending to force the fluid along the pipe is 10 + 15, or 25 feet. Similarly, if a gas-pipe rise from a gas-holder to a district lying 20 feet higher, and discharge there, the levity of a column of gas 20 feet in height must be added to the gas-holder pressure in order to obtain the true motive force.

There is yet another consideration under this head which deserves notice. We have hitherto supposed the discharging end of the pipe to be open, or, which is the same thing, the pressure at that end to be = 0. This however is by no means necessary to the application of the rules; for, if the discharging end is also under pressure, we have only to take the *difference* between the pressures at the two ends of the pipe, and to use this precisely as before.

The following rule will therefore serve universally, whatever be the position of the pipe, or the pressure to which the fluid is subjected.

From the pressure at the supply end of the pipe, deduct the pressure at the discharging end; then add or subtract, as the case may require, the gravitating influence of a column of the fluid equal in height to the difference of level (if any) of the two ends of the pipe: the result will be the true motive pressure or head, and may be used as such in the rules.

Disturbing Causes.

We have hitherto supposed the pipe to be straight, and free from any influences tending to check the passage of the fluid, except that of the friction along its sides. There are however, in practice, other causes which affect the question; and, although most of them are scarcely capable of being reduced to rule, it is right they should be noticed here.

As a general principle, it may be remarked that all causes which tend to produce eddies, or disturbance of the particles of the fluid among each other, must inevitably check the velocity and diminish the discharge. Every particle of matter, once set in motion, tends to continue moving on in a straight line, and carries with it a certain amount of momentum, or *vis viva*, which it received at first starting. Whenever therefore the free forward motion of any portion of the fluid moving in a pipe is checked, a disturbance of the particles must take place among themselves, by which a portion of the *vis viva* is absorbed or destroyed,

and a general diminution of velocity produced, which cannot be regained except by a fresh expenditure of moving power. Any one who will watch the course of an open stream of water, must soon observe the remarkable effect of eddies or disturbances in checking the velocity; and it must be obvious if the same causes are allowed to operate in closed pipes, where the velocity is generally much greater, the same results must follow in an increased degree.

The following may be particularized as some of the disturbing causes which affect the discharge of fluids through pipes:—

1. There may be some loss from the mode by which the water enters the pipe from the reservoir. If a round hole is made in the thin side of a tank (or what is termed on the continent an "*orifice en mince paroi*"), the quantity of water flowing out will be only about $\frac{6}{10}$ of that due to the head and area according to the rule embodied in Equations I. and II., this reduction being caused by what is called the contraction of the vein. If, now, a pipe or "adjutage" be fitted upon the hole, its length being about two or three times its diameter, the quantity will be increased to about $\frac{8}{10}$. If, again, the pipe be bell-mouthed towards the reservoir in a particular shape, the quantity will be increased to very nearly its theoretical amount.

Of course therefore the manner in which the entrance of the pipe is constructed must affect the quantity discharged; and, as this is often in practice complicated by the introduction of valves or sluices, it is impossible to reduce it to rule. It must be remarked however that, as this cause only affects the second term of the denominator in Equation VII., it may be dismissed altogether if the pipe be of considerable length in proportion to its diameter.

2. *Bends* in the pipe have also a tendency to reduce the velocity, and, consequently, to lessen the discharge. It is evident that, if a sharp bend occur in a pipe in which a fluid is moving with considerable velocity, the particles, being suddenly diverted from the right line in which they naturally tend to move, will be caused to eddy, or become agitated among each other, and thus, as before explained, a portion of the *vis viva* will be absorbed, and the velocity to some extent reduced accordingly.

The investigation of the increased resistance arising from bends has been attempted by mathematicians, but with very little success. The ordinary formula, as used by English writers, is as follows:—If $v =$ the velocity of the fluid in the pipe, $\phi =$ the angle of the bend, and $h =$ the head of water necessary for overcoming the additional resistance caused by the bend; then

$$h = A\, v^2 \sin.\, \phi.$$

where A is some constant.

It only requires however a very simple examination to show that this formula is, on the face of it, inapplicable and absurd.

In the first place, it is well known to all who have had to do with pipes, that in ninety-nine cases out of a hundred the bends are not made sharp elbows, but are more or less curved; and it is a fact consistent alike with experience and with common sense, that, in proportion as the bend is curved with a larger radius, its disturbing effect upon the passage of the fluid becomes less in amount, until, if the curve be much expanded, the additional resistance may be said practically to vanish altogether. Now the above formula contains no element whatever representing the radius of the bend; and therefore it would give the same resistance for a sharp elbow as for a curve of any radius whatever, no matter how large.

Secondly, it stands to reason that two bends of any given angle, placed together, should give double the resistance caused by one of them alone; at least it is difficult to imagine any reason why it should not be so; but this does not accord with the rule, according to which the resistance of a bend of 90° would be only 40 per cent. greater than one of 45°!

Thirdly, above a right angle, the sine *decreases* as the angle *increases;* so that by the rule, provided the bend be above 90°, the resistance would appear to become less as the bend becomes greater, until at 180°, *i. e.* with a bend of a complete semicircle, it vanishes altogether!

It is certainly marvellous that a rule of such a preposterous nature, and producing such evidently absurd results, should for a moment have been received or promulgated. The fact is that the English writers on hydraulics, in copying from Dubuat, who established a rule for the resistance of bends, have misapplied a quantity which he termed the "*angle de réflexion,*" by substituting for it the angle of the bend; and have thus misinterpreted his views, and introduced a rule altogether inappropriate to the case in point*. It could be easily shown that, by a correct application of Dubuat's principle to curved bends, a formula might be deduced which would be free from the defects of the one above named, and would appear to be reasonably applicable to the case in question; but as, unfortunately, we are not in a position to test it by experiment, we should be acting at variance with the principle on which we set out, to recommend it for use in practice. The

* It is believed that this is the first time the mistake here alluded to has been pointed out.

few experiments which have been made upon the effect of bends do not appear to lead to any satisfactory result; and M. D'Aubuisson, whose researches on fluids are of great authority, was compelled to acknowledge that his attempts to establish a rule for them had all been in vain.

We are inclined to believe that in ordinary cases, if the bends are constructed with a radius tolerably large in proportion to the diameter of the pipe, the resistance is but of trifling amount; but that it may be considerable if the angle is sharp, and the velocity high.

3. Loss may also be occasioned by contraction or "throttling" in the pipe. If at any point in the length the aperture is diminished in area, the velocity must be increased at that point, which produces a corresponding increase of friction. Besides which, if the contraction be sudden, there is the additional loss by eddying and disturbance of the particles in entering the throttled part, and making their exit from it into the full bore of the pipe again. This last effect may be neutralized, if, where a contraction is necessary, the reduction in area be made gradually and smoothly, without any sharp or abrupt angles for the fluid to impinge against; for this purpose, in practice, "reducing pipes" of a conical shape are used. With this precaution the loss by occasional contraction is not considerable. M. D'Aubuisson found, by an experiment on the Toulouse Water-works, that a diminution of the pipe, in one place, of $\frac{94}{100}$ its area, produced only $\frac{1}{100}$ diminution in the quantity discharged.

4. It is singular, but not the less true, that *enlargements* of a pipe will often produce a greater loss than contractions. Venturi found that, by putting five large aneurisms on a tube, he diminished the discharge nearly 40 per cent. The cause of this is, of course, entirely due to the eddying of the fluid in the enlarged spaces, and the disturbance in the motion of the particles caused thereby. It may be diminished by adopting the precaution mentioned in the last case, namely, by making the alterations of form and dimension as smooth and gradual as possible.

5. There are many other causes of a minor kind which all more or less affect the discharge of a fluid through a pipe: such, for example, are irregularities of form of the pipe; accidental protuberances or vacuities; roughness of surface; sharp projections or cavities at the junctions, if imperfectly made; the peculiar form or arrangement of cocks, valves, or sluices; incrustations upon the internal surface of the metal; fixed deposits in the low parts of the pipe; leakage; or (in water-works) collections of air in the upper parts; the pipe not running full; and

so on. All these must have more or less influence on the velocity of the current, according to the degree in which they prevail in any particular case.

Now, since disturbing causes of the nature above described must exist to a greater or less extent, in almost every practical instance of the conveyance of fluids in pipes; and since it is manifestly impossible to comprehend their effects in any method of calculation which shall be simple enough for general use, we must be content to adopt rules which will come tolerably near the truth when applied to practice. We cannot expect the results of experiment and calculation absolutely to coincide, but must rest satisfied if we find them approach within a reasonable limit of each other. Every prudent practical man knows the necessity of leaving a margin in his calculations for incidental or unforeseen disturbing causes, and therefore, in taking general approximate rules for his guide, he is enabled to arrive at a sufficiently accurate result.

And here it will be observed that the method of completing the formula by the aid of experiment has peculiar advantages in practical application; inasmuch as we introduce by that means the effect of the disturbing causes insensibly into the calculation. For, if the experiments are conducted on a sufficiently practical scale, they must of necessity be more or less affected by irregularities; and any constant deduced from a mean of such experiments will therefore carry with it the mean effect of the disturbing causes which arise in practice. It is the business of the skilful and educated experimenter so to choose and regulate his experiments as to keep this end constantly in view.

There is another point of importance which is not always kept in view by the framers of formulæ—that is, that it is far better to make the rule *simple* (provided, of course, that its true principles are approximately maintained), than, by a complicated formula, to strive after an exactitude which we cannot, after all, hope to attain. The simple rule will often attract the practical man to its use, when the complicated one will frighten him away from it altogether. For the same reason it is desirable in coefficients to employ round numbers, if possible, instead of tiring the patience with a useless array of decimals.

Comparison of the Formulæ with Experiment.

We have now only to show a comparison of the results of actual experiment with those given by the formulæ. It is much to be regretted that so few good experiments on this subject are to be found; for, although the results appear to agree tolerably well, yet it must be remembered that the constant coefficients in

the equations have been deduced broadly from a very small collection of data; and it is therefore quite possible that more numerous and varied experiments may show that they ought to receive some degree of modification. For this reason we would invite the publication of any other experiments that may lie within the knowledge of our readers, as it is only by a comparison of a great number of these, obtained under widely differing circumstances, that the general applicability and correctness of the formulæ can be ensured*.

Experiments on Atmospheric Air.

No.	Diameter of Pipe.	Length of Pipe.	Pressure in Inches of Water.	Quantity actually discharged.	Quantity calculated by Equa. XIII.	Difference per Cent.
	Inches.	Yards.		Cubic feet per hour.	Cubic feet per hour.	
1	0·62	7·2	1·34	183	170	7½
2	„	41	„	73	74	1
3	„	62	„	62	60	3
4	„	93	„	52	49	6
5	„	119	„	42	43·5	4
6	„	138	„	39	40·2	3
7	„	141	„	38·7	39·8	3

The above were tried by M. Girard in Paris, and are recorded in D'Aubuisson's 'Hydraulique,' Art. 525.

* For the benefit of such of our readers as may dislike the algebraical form of the rules, we may put Equation No. IX. into words, as follows:—

(1.) Multiply the pressure by the diameter of the pipe, both in inches.

(2.) To the length of the main in yards, add the diameter in inches, and multiply the sum by the specific gravity of the gas. Divide the product by the result of (1), and extract the square root of the quotient.

(3.) Multiply the square of the diameter of the pipe, in inches, by the constant coefficient 1350, and divide by the result of (2). The quotient will be the quantity discharged, in cubic feet per hour.

The following shows Experiment No. 10 worked out in figures, as an example:—

1. $3 \times 10 = 30.$

2. $\sqrt{\dfrac{(1760 + 10) \times 0{\cdot}4}{30}} = \sqrt{23{\cdot}6} = 4{\cdot}86$

3. $\dfrac{100 \times 1350}{4{\cdot}86} =$ 27,810 cubic ft. discharged per hour by a pipe 10 inches diameter, with pressure of 3 in.

Experiments on Coal Gas.

No.	Diameter of Pipe.	Length of Pipe.	Pressure in Inches of Water.	Specific Gravity of Gas.	Quantity actually discharged.	Quantity calculated by Equa. XIII.	Difference per Cent.
	Inches.	Yards.		Air = 1.	Cubic feet per hour.	Cubic feet per hour.	
1	0·62	41	1·34	0·559	99	99	0
2	0·62	62	1·34	0·559	83	82	2
3	0·62	93	1·34	0·559	74	66	12
4	0·62	119	1·34	0·559	57	58	2
5	0·62	138	1·34	0·559	53	54	2
6	18	1,760	1	0·4	66,000	69,000	4½
7	0·5	10	1·25	0·4	120	129	7
8	0·5	59	1·25	0·4	60	55	8
9	10	100	3	0·4	120,000	112,000	7
10	10	1,760	3	0·4	30,000	27,810	7
11	2	25	0·5	0·528	1,630	1,440	11½
12	26	3,130	0·8	0·42	103,000	114,000	10
13	26	4,300	2·25	0·42	175,000	166,000	6
14	26	4,300	0·475	0·42	80,000	76,000	5

EXAMPLES FOR PRACTICE IN THE PASSAGE OF GAS THROUGH PIPES.

To find the Quantity of Gas discharged.

It is required to find the number of cubic feet of gas, of the specific gravity of ·420, which will be discharged from a pipe 6 inches diameter and 1760 yards in length, under a pressure of ·5, or half an inch head of water.

The formula is $$Q = 1350\ d^2 \sqrt{\frac{h\ d}{s\ l}}$$

i. e. Multiply the pressure in inches of water by the diameter of the pipe also in inches. Divide the product by the specific gravity of gas multiplied by the length of pipe in yards. Extract the square root of the quotient, which root, multiplied by the constant quantity 1350 and the square of the diameter in inches, gives the number of cubic feet discharged in one hour.

Thus $(h\ d) = 6 \times \cdot 5 = 3 \cdot 0$.

$$\left(\sqrt{\frac{h\ d}{s\ l}}\right) = \frac{3 \cdot 0}{\cdot 420 \times 1760} = \cdot 00405, \text{ whose square root } = \cdot 063.$$

$$\left(1350\ d^2 \sqrt{\frac{h\ d}{s\ l}}\right) = 1350 \times 36 \times \cdot 063 = 3061 \cdot 8 \text{ cubic feet} = \text{Q}.$$

To find the quantity discharged from a pipe of any other length, the remaining conditions being the same.

Say, as, required quantity discharged,
is to, given quantity discharged,
so is, the square root of the length of new pipe,
to, the square root of the length of given pipe.

The formula for direct calculation is $l = \dfrac{135^2\ d^5\ h}{s\ \text{Q}^2}.$

Next, suppose we want to ascertain the pressure in inches of water to discharge a certain quantity of gas of given specific gravity in an hour through a pipe whose dimensions are known. We have, as before,

$$\text{Q} = 1350\ d^2 \sqrt{\frac{h\ d}{s\ l}}$$

$$\text{Q}^2 = (1350)^2\ d^4\ \frac{h\ d}{s\ l}$$

$$= \frac{(1350)^2\ d^5}{s\ l} \cdot h$$

$$\therefore h = \frac{\text{Q}^2\ s\ l}{(1350)^2\ d^5}$$

i. e. To find pressure: Multiply the square of the number of cubic feet of gas discharged in one hour by the specific gravity of gas, and again by length of pipe in yards. Divide the product by the square of the constant 1350, multiplied by the diameter in inches raised to a fifth power, and the quotient gives the pressure.

Example. Let the length of the pipe be 1760 yards and diameter 10 inches, required pressure in inches of water to discharge in an hour 30,000 cubic feet of gas, whose specific gravity equals ·4.

$$\frac{\text{Q}^2 \times s \times l}{1350^2 \times d^5} = \frac{900{,}000{,}000 \times 1760 \times \cdot 4}{1{,}822{,}500 \times 100{,}000} \times \frac{633{,}600{,}000{,}000}{182{,}250{,}000{,}000} = 3 \text{ nearly.}$$

To find the Diameter.

The diameter of a pipe is required which will discharge a certain given quantity of gas, under a given pressure, in a known length. We have,

$$\text{Q} = 1350\ d^2 \sqrt{\frac{h\ d}{s\ l}}$$

$$Q^2 = (1350)^2\ d^4\ \frac{h\ d}{s\ l} \text{ by squaring the equation,}$$

$$= \frac{(1350)^2\ h}{s\ l} \cdot d^5$$

$$\therefore\ d = \sqrt[5]{\frac{Q^2\ s\ l}{(1350)^2\ h}}$$

which can only be calculated by a table of logarithms.

$$\log.\ d = \tfrac{1}{5}\left\{ 2 \log.\ Q + \log.\ s + \log.\ l - 2 \log.\ 1350 - \log.\ h \right\}$$

Example. It is required to find the diameter of a pipe, 1760 yards long, to discharge 66,000 cubic feet of gas, of the specific gravity of ·4, in one hour, with a pressure of 1 inch.

2 log. Q = 2 log. 66,000	=	9·6390878
log. s = log. ·4	=	1·6020600
log. l = log. 1760	=	3·2455127
		12·4866605
2 log. 1350 = 6·2606676 ; log. h = log. 1 = 0·0000000 . . .	=	6·2606676
	5)	6·2259929
log. d	=	1·2451986

$\therefore\ d = 18$ inches nearly.

By reference to the table the discharges of gas under one-inch pressure, from pipes 2 to 24 inches diameter, will be found; if the discharge from a pipe of the same diameter, but with any other length and pressure, be required, it is easily found by calculation.

Discharges of Gas of Specific Gravity ·420, in Cubic Feet per Hour, with a pressure of 1 inch Head of Water.

Lengths of pipes in yards.	DIAMETERS OF PIPES IN INCHES.															
	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XII.	XIV.	XVI.	XVIII.	XX.	XXII.	XXIV.
20	2,291	7,253														
30	2,149	5,941	12,160	21,262												
40	1,859	5,127	11,340	18,192	28,965											
50	1,666	4,580	9,417	16,367	25,758	38,168	53,308									
100	1,177	3,244	6,652	11,643	18,322	26,989	37,670	50,519	65,475							
150	961	2,653	5,421	9,483	14,968	21,027	30,758	41,334	53,970	84,758	124,362					
200	833	2,284	4,708	8,209	12,976	19,051	26,611	35,757	46,575	73,288	107,950	150,681	201,986			
250	745	2,053	4,212	7,357	11,566	17,066	23,846	32,367	42,580	65,703	96,579	134,774	179,252	235,440	300,564	
300	679	1,871	3,844	6,716	10,594	15,479	21,686	29,196	37,935	59,875	88,111	123,033	164,899	214,920	272,467	392,418
400	589	1,615	3,326	5,804	9,136	13,594	18,576	25,259	32,845	51,904	76,204	106,464	139,530	186,840	235,877	344,050
500	529	1,433	2,980	5,129	8,164	12,039	16,848	22,526	29,430	46,461	68,266	95,785	127,714	164,700	211,048	308,458
600	480	1,324	2,721	4,725	7,481	10,970	15,292	20,557	26,865	43,379	62,181	87,145	116,785	151,740	192,753	281,080
700	442	1,227	2,505	4,307	6,901	10,187	14,169	19,026	24,840	39,288	57,682	80,924	108,037	140,400	177,071	260,091
800	. .	1,142	2,354	4,083	6,463	9,526	13,305	17,824	23,220	36,547	53,978	75,740	101,039	131,220	166,617	243,664
900	. .	1,081	2,203	3,847	6,075	8,996	12,268	16,839	21,870	34,599	50,803	71,248	95,653	124,200	158,122	228,062
1,000	. .	1,020	2,095	3,678	5,783	8,533	11,836	15,965	20,790	32,853	48,157	67,382	90,541	117,720	148,975	218,111
1,760	. .	. .	1,576	2,767	4,374	6,416	8,985	12,137	17,010	24,688	36,250	50,803	68,234	88,560	112,384	164,268
2,640	. .	. .	1,296	2,261	3,547	5,225	7,257	9,841	12,690	20,217	29,635	41,512	55,549	72,360	91,476	134,152
3,520	. .	. .	1,123	1,957	3,013	4,498	6,307	8,529	11,070	17,526	25,686	35,942	48,114	62,640	79,061	115,900
5,280	. .	. .	. .	. .	2,527	3,704	5,184	6,889	9,040	14,191	20,905	28,030	39,366	50,760	64,680	94,910
7,040	. .	. .	. .	. .	. .	3,175	4,496	6,014	7,836	12,247	17,992	25,228	34,117	44,280	55,892	82,134
8,800	. .	. .	. .	. .	. .	. .	. .	5,358	7,020	10,886	16,140	22,464	29,305	39,420	50,311	73,008
10,000	. .	. .	. .	. .	. .	. .	. .	. .	. .	10,303	15,082	21,081	28,431	36,720	47,044	68,445

SERVICES.

Gas Companies have now, with very few exceptions, resigned the internal arrangements for lighting buildings with gas, into the hands of "fitters," and were these tradesmen all good workmen, and all honest, there would be no objection to such resignation; but there are a large number of them who do not seem to have the least idea that a gas-pipe need be of any particular size or material, in any particular direction, or indeed even tight; and the companies have not acted wisely in losing all control over the acts of these people; for imperfect fittings have done much to prevent the universal use of gas in private houses, a source of revenue of much importance. It is probably not advisable that they should have a staff of fitters in their direct employment, as it would entail several small inconveniences as well to be avoided, and small companies in particular could not provide constant work for perchance even a single hand; but both large and small might give authority to a certain number to lay on services, who should be liable to lose their license should accident occur, traceable to defective work. It is difficult to conceive any objection to this, but it will never be done notwithstanding; and consumers therefore must defend themselves by employing thoroughly competent fitters only, of which there are a tolerable number in London* and all large provincial towns.

A chapter on services may be considered superfluous, yet as the book would not be complete without one, the following brief comments are submitted. There are two distinct descriptions of services, viz. the Company's and the Fitter's or House services.

All gas companies lay on a certain length of pipe from their mains free of charge to any consumer. In London and most towns, this service is taken through the wall of the house. In country districts the services are generally only taken from the main across the footpath, or to a certain number of feet from the main; the remaining portion being done at the consumer's expense. The company's services consist of lengths of wrought-iron lap-welded tubing, united together by screw-sockets, and laid with a slight fall towards the main. The manufacture

* The names of Edge, Cottam and Hallen, Hulett, Deane, Verity, etc., may be noticed.

of this tubing is now brought to great perfection, and Mr. Russell, the first inventor of the process, is still one of the best makers.

For changing the direction or uniting the chief service with branches, there are bends, elbows, T-pieces, and crosses made, which require no description.

House or Fitter's services should be of drawn pewter or tin tubing, up to one inch, when they are generally of wrought-iron.

It is desirable that all bends should be circular, but it is impossible to make them so in many instances, as they would have an unsightly appearance. No branch ought to proceed from a service of a quarter of an inch in the bore, and no more than two from a three-eighth service. All pipes, before they are fixed, must be proved by condensing air into them by means of a hand-syringe while under water; the leak will be easily detected by the air-bubbles which rise through the water. If all the fittings rise from the main no siphon is necessary, but if any part of them fall below the main a small receiver must be attached to the lowest point, fitted with a screw-plug at the bottom, so that any moisture may be drawn off. The pipes which convey the gas to the burners must be in as direct a line as possible, to avoid unnecessary expense and obstructions. The union joints used to connect two services together must be of the same diameter as the pipes, and soldered firmly on to them. It is customary with workmen when they prove their pipes to coil them up, place their thumb over one end and suck the air out from the other; if the tongue adheres, it is a proof of a vacuum existing in the pipe, which is therefore faultless.

The following table gives the theoretical diameter required for services which have to supply a certain number of burners, at distances from the street-main. The table is calculated by the formula $d = \sqrt[5]{\frac{Q^2\, s\, l}{(1350)^2\, h}}$ being the same as that used in the determination of the quantities of gas delivered by large pipes; but in practice the discharges from the latter are found to be greater, and from the former less, than that given by calculation. The services are made to increase in diameter by eighths of an inch, and if the next largest diameter to that given by the table be taken, it will be found correct. Thus suppose 100 lights had to be supplied at 100 feet from the main. The tabular diameter is 1·13 inch; if the pipe be made $1\frac{1}{4}$ diameter, it will be sufficient; for 20 lights the diameter will be $\frac{3}{4}$ inch; for 40 lights 1 inch; for 150 lights $1\frac{1}{2}$ inch; for 200 lights $1\frac{3}{4}$ inch; and for 300 lights 2 inches. The pressures, lengths of pipe, and number of burners other than those mentioned in the table, will be found by the rules given in the chapter on Street Mains.

Table showing Diameter of Pipes, in decimals of an inch, to supply Lamps at certain distances from the Main.

Distance of lamps from main in feet.	Number of Lamps, each burning five feet per hour, with a pressure of 1 inch.												
	3.	5.	10.	15.	20.	25.	30.	40.	50.	100.	150.	200.	300.
5	·15457	·18882	·24912	·29424	·32876	35·946	·38824	·43381	·47430	·62577	·73911	·82581	·97525
10	·17682	·21691	·28617	·33660	·37765	·41291	·44415	·49832	·54484	·71881	·83775	·94862	1·1157
15	·19176	·23524	·31034	·36504	·40956	·44779	·48167	·54041	·59086	·77954	·91693	1·0288	1·2099
20	·20311	·24916	·32872	·38666	·43381	·47429	·51019	·57241	·62585	·82571	·97123	1·0897	1·2815
30	·22027	·27020	·35649	·41932	·47045	·51438	·55329	·62076	·67872	·89546	1·0533	1·1817	1·3898
40	·23331	·28620	·37760	·44415	·49830	·54483	·58605	·65753	·71891	·94848	1·1156	1·2517	1·4721
50	·24396	·29927	·39483	·46441	·52105	·56970	·61280	·68753	·75172	·99177	1·1665	1·3089	1·5393
60	·25302	·31024	·40950	·48167	·54041	·59086	·63556	·71307	·77928	1·0286	1·2099	1·3574	1·5965
70	·26094	·32010	·42231	49·675	·55733	·60936	·65546	·73540	·80405	1·0608	1·2478	1·3999	1·6464
80	·26802	·32876	·43375	51·255	·57241	·62585	·67011	·75530	·82582	1·0895	1·2874	1·4378	1·6910
90	·27439	·33660	·44408	·52235	·58606	·64077	·68925	·77331	·84550	1·1155	1·3121	1·4721	1·7313
100	·28023	·34377	·45354	·53348	·59854	·65442	·70393	·78978	·86351	1·1394	1·3400	1·5035	1·7681
150	·30391	·37281	·49185	·57054	·64909	·70970	·76339	·85649	·93688	1·2356	1·4532	1·6305	1·9175
200	·32191	·39489	·52098	·61281	·68753	·75173	·80860	·90720	·99191	1·3088	1·5393	1·7270	2·0311
250	·33660	·41291	·54476	·64077	·71891	·78604	·84550	·94862	1·0371	1·3685	1·6095	1·8058	2·1238
300	·34901	·42825	·56507	·66457	·74561	·81523	·87691	·98389	1·0757	1·4197	1·6693	1·8729	2·2540

A useful little book has lately been published by Mr. J. W. Parker, West Strand, entitled, 'Hints to Gas Consumers,' from which I have taken the following extracts :—

"The excessive cost and defective construction of fittings have in numerous instances tended more than anything besides to engender prejudices against gas, and more particularly in private houses. No greater annoyance can well be imagined than, after expending a considerable sum in fitting up one's premises, to have the odour of gas diffused throughout the most frequented apartments. This can only happen through defects in the fittings, or from ignorance, or culpable neglect on the part of those whose duty it is to open and close the cocks by which gas is admitted to the burners.

"Gas-fittings ought to be made of the best materials; they should be judiciously arranged, and fixed by sober and skilful workmen. The choice of a situation for the main cock is of importance; it should be placed as near as possible to the inside of the wall through which the gas is admitted from the street-main, and where it will at all times be accessible to the inmates of the house. The key or *spanner* by which it is turned should always be attached, and the nick which indicates whether it is open or shut should be distinctly marked. The cock should be literally a *stop*-cock, a caution applicable to all gas-cocks; for it has of late become so much the fashion, in studying the *ornamental,* to neglect the *useful,* that even a practised hand is sometimes at fault. Whatever be the style of fittings, however massive or rich in embellishment, the stop-cocks should be made on one uniform principle, and the more simple they are the better.

* * * * * * *

"Throughout their various ramifications the pipes should have a slight inclination towards the point where the main-cock is fixed, and thence to the street-main; this is to allow the water, which is occasionally deposited in them, to drain off without interrupting the passage of the gas. In fittings which are not thus arranged the water accumulates in some curvature of the pipes, and occasions an oscillation, or, as it is very commonly called, *jumping* of the lights. When this happens, the first thing to be ascertained is, whether the cause be *general* or *partial;* that is, if it exist in the street-mains, or in the consumer's fittings. If the lights in the immediate neighbourhood, and which are supplied from the same main, burn steadily, it is a proof that the obstruction is in the fittings; but if *they* oscillate, it is in the main, of which immediate notice should be sent to the office of the Company.

* * * * * * *

"Under particular circumstances, it is impossible to fix the pipes in the way we have mentioned, so that they may all incline towards the street-main. In that case the lowest point must be fitted up with what is usually, but very improperly, called a *siphon,* and which consists of a short piece of tubing with a stop-cock near its extremity. Hither the condensible products will flow, and may be drawn off periodically.

* * * * * * *

"Where it can be done without inconvenience, it is a good plan to turn off the main-cock at night, thereby excluding gas from the premises."

* * * * * * *

Mr. Parker's work is full of useful instruction, and I cannot do better than refer my readers to it for further information on the subject of fittings and consumers' meters.

BURNERS.

WHILE the engineer labours at the works to procure the most perfect gas from his coal, and relies upon the truth of his calculations for the quantity required by the consumers' lamps, he must not forget that the effect his operations will produce depends much upon the manner in which the gas is burnt. Since the publication of the first edition of this work there have been a great number of patents taken out for "improved" burners; some of them are well arranged to effect their object, viz. the complete combustion of the gas, others are very imperfect, and some have taken the form of those used in 1805; I shall notice the most useful further on.

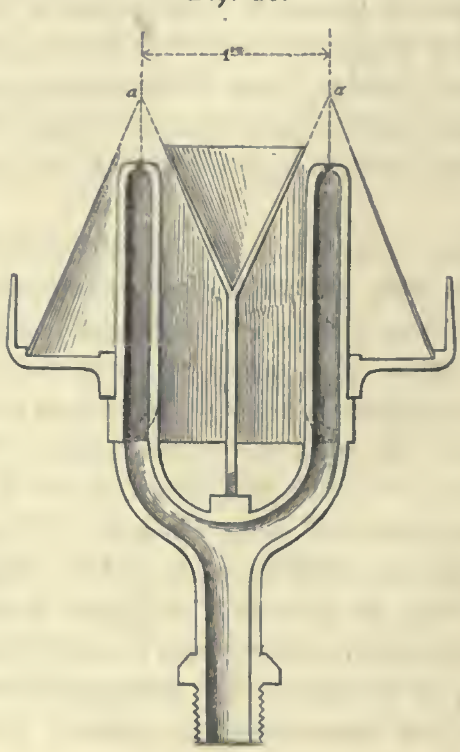
Carburetted hydrogen of the specific gravity ·400 (which is about the density of ordinary London gas when arrived at the point where it has to be burnt), requires two volumes of pure oxygen for its complete combustion and conversion into carbonic acid and water. Atmospheric air contains, in its pure state, twenty per cent. of oxygen; in populous towns less; but twenty per cent. is near enough for the present purpose. One cubic foot of carburetted hydrogen then requires for its proper combustion ten cubic feet of air; if less be admitted on to the flame a quantity of free carbon will escape (from its not finding a proper volume of oxygen for conversion into carbonic acid), and be deposited in the form of dense black smoke. When the flame from an Argand burner is turned up high, the air which rushes through the interior ring becomes decomposed before it can reach the air on the top of the flame, which consequently burns in one undivided mass, the gas being in part unconsumed, the products unconverted, and carbon deposited abundantly.

If an excess of air be admitted, it would appear at first to be of no consequence; but we shall find upon examination that the quantity of nitrogen accompanying this excess has a tendency to *extinguish* the flame, while it takes no part in the elective affinity constantly going on between the several elementary gases, viz. hydrogen, oxygen, and the vapour of carbon; and also that the quantity of atmospheric air passing through the flame unchanged, tends to reduce the temperature below that necessary for ignition, and therefore to diminish the quantity of light.

For the proper combustion of the gas, neither more nor less air than the exact quantity required for the formation of carbonic acid and water can be admitted through the flame without being injurious. It is not possible practically to regulate the supply of air to such a nicety; we therefore prefer to diminish the quantity of light by having a slight excess of air, rather than to produce smoke by a deficiency, the former being unquestionably the least evil.

In the year 1815, Mr. Clegg and Mr. Grafton commenced a series of experiments upon the best form of burner, the principal object in view being to regulate the supply of air to the flame.

Fig. 40.



The woodcut Fig. 40 represents the kind of burner finally determined upon as the best. The burner itself was an Argand, one inch in diameter within the drilled ring of jets, which, with a flame three inches high, consumed five cubic feet of gas in an hour. For the complete combustion of that gas, fifty cubic feet of air are required. To regulate the admission of the air to the flame, an exterior cone was supported upon the gallery bearing the glass chimney. The interior of the flame was supplied with air through the space left between the upper rim of

an inverted cone and the interior edge of the lamp. The combustion of the gas was further improved by the air being made to rush towards a point *a*, which it is evident would be its direction. The interior cone was made to adjust upon its supporting wire, and its annulus increased or diminished at pleasure.

This burner has lately been *patented* under the name of the double-cone burner: certainly no contrivance would better deserve an exclusive privilege had it been original, for this description of burner is by far the best Argand, and should be universally adopted. An Argand burner three-quarters of an inch in diameter within the drilled ring, with a flame $2\frac{1}{2}$ inches high, consumes $3\frac{1}{2}$ cubic feet per hour, and will require thirty-five cubic feet of air for the proper combustion of the gas. A burner half an inch diameter will consume $1\frac{3}{4}$ cubic feet of gas per hour with a flame $1\frac{3}{4}$ inch high, and require $17\frac{1}{2}$ cubic feet of air for its combustion. The distance between the holes in the drilled ring should be so much, that the jet of gas issuing from each, shall, when ignited, just unite with its neighbour; this arrangement produces a greater amount of light than when the holes are further apart, because while perfect combustion is attained, the quantity of air passing between the jets of gas is not so much as to be prejudicial; when the holes are thus close together, the size of the burner may be computed from the diameter of the drilled ring; when however the holes are so far apart as to exhibit distinct jets of flame, the size of the burner may be computed from the number of them.

As before observed, the true principle on which to make an Argand burner is so to form its air-channels that they may just supply the burning gas with atmospheric oxygen enough for complete combustion, and no more. Each sized burner should have its own height of flame, and the cones should be capable of adjustment by the maker, so that the lamp will smoke if turned up higher than this. Mr. Platow's double cone burner, for instance, is a very close approximation to the true form; and from the intelligence of Mr. Hulett, the present maker, there is every probability that it will be soon manufactured in perfect proportion. The body of the burner is too short within the glass, and the cones admit too much air, both of which defects are easily remedied. The body of the burner should be long between the stem and jets, that the gas may be heated as it passes to be burned; and on this principle it is presumed Mr. Leslie contrived his burner; but instead of heating the gas in a close chamber, as in a common Argand, he brings up a number of small tubes from the bottom ring. It is very true that the gas thus becomes more heated than in the common burner, but the spaces between the tubes admit a superabundance of air, which cools the gas during

combustion; the result is a less quantity of light with the same quantity and quality of gas than is due to the common Argand, as the following photometric results show:—

Common Argand, 15 *holes, length of chamber* $1\frac{1}{16}$ *inch.*

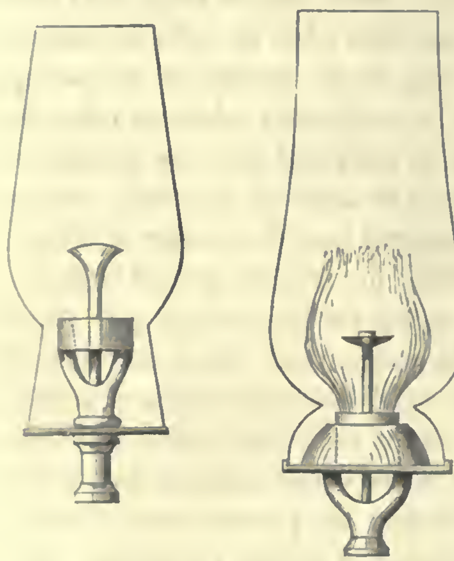
6 Cubic feet of gas per hour, equal to . . .	17·42 candles.
5 „ „ „ „ . . .	13·64 „

Leslie's burner, 28 *holes, length of tubes* $1\frac{3}{8}$ *inch.*

6 Cubic feet of gas per hour, equal to . . .	14·73 candles.
5 „ „ „ „ . . .	11·28 „

The experiments were made on the same evening with the same gas, and shadow photometer; the candle was of spermaceti, consuming 123·16 grains per hour.

Fig. 40ᵃ. *Fig.* 40ᵇ.



Scale 4 inches to a foot.

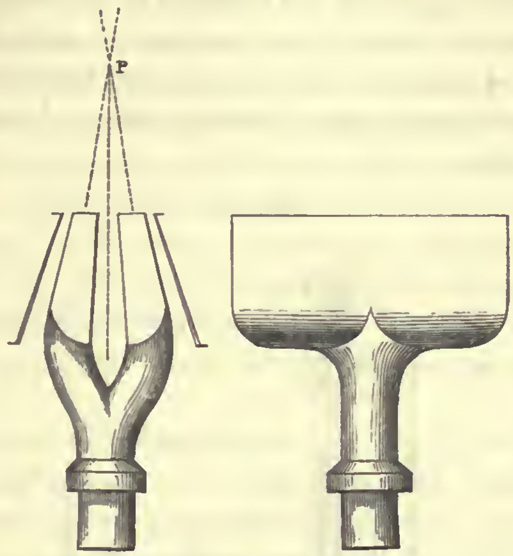
The National burner (Fig. 40ᵃ) is arranged so that the chimney-glass, by being contracted at the line with the drilled ring of jets, forms the outer air-passage, and the button diverging the air passing through the inner opening of the burner, spreads the flame out into a thin sheet, causing it to produce a very white light at the upper part, but a bluish cold flame at the lower. This burner also gives less light with the same quantity of gas than the common long-chambered Argand.

The Sun burner (Fig. 40ᵇ), made by Messrs. Dean and Co., is an improvement upon the former: the body of the burner is longer, and the quantity of air is more limited; the photometric results are better in consequence. The gas issues from a continuous ring, instead of from a series of holes; and where a mass of light is required, without a strict regard to the quantity of gas consumed, this burner is eminently qualified to give it.

Another kind of burner, which produces a very intense light, is the double Argand, similar in make to two common Argands placed one within another, the admission of air to the flames being regulated in the same manner as described

above; the space between the concentric flames should be so small as to require no adjustment, and yet large enough completely to separate them*. A glass chimney must of course form an essential appendage to every Argand lamp, its use being to create a draught and direct the current of air through the flame.

Fig. 41.



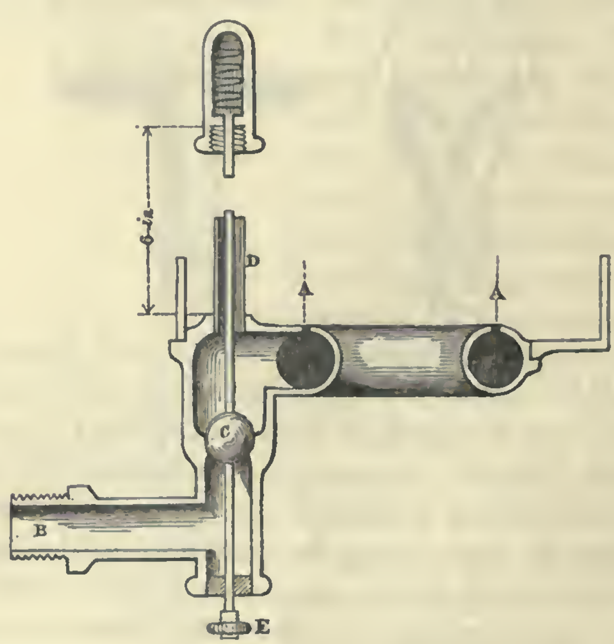
The second series of experiments were made upon a burner represented in Fig. 41, formed of two parallel plates inclining towards each other, so that the gas might be directed towards a point P, about three-quarters of an inch above the orifices from which it issued. The space between the plates was just sufficient to admit the proper quantity of atmospheric air; the supply to the exterior of the flame was regulated by plates having the same effect as the larger cone in the Argand lamp, and adjusted for the proper supply of air in the same manner. The ignited jets of gas proceeding from the drilled parallel plates were separated by the rush of the air between them. The holes in each plate were drilled so that the hole in one plate was opposite the space between two in the other. The light produced was intense, more so than could be attributed to the mere regulation of the air. The same brilliancy is produced if two candles are inclined towards each other, so that their flames will just touch; both will immediately burn with a white light, and the quantity be increased more than a third, which

* A burner of this description was fixed on the staircase to the House of Commons in 1815, where it remained until the fire in 1834.

can easily be proved by the test of relative shadows with the photometer. A greater quantity of light can therefore be produced from the same quantity of gas by using this description of burner. If the chambers of a double Argand were thus inclined towards one another, the result would doubtless be an augmentation of light from the same quantity of gas over those with parallel chambers.

Fig. 42 represents a burner that was contrived by Mr. Clegg in 1813, to silence some objections that were raised by the Insurance Companies against the use of gas, and mentioned at page 16. It is too expensive for general use, but may be applied in vaults and confined places, where the escape of gas from an open lamp might cause an explosion.

Fig. 42.



A A is the drilled ring, from which the gas is burnt.

B is the inlet for the gas.

C is a valve which closes when the brass tube D cools, and prevents the escape of the gas.

When the lamp is to be lighted the valve is lifted by pressing the button E upwards with the thumb; the expansion of the rod D, by the heat of the flame, retains it in this position, and when the flame is extinguished the valve is suffered

to fall on to its seat by the contraction of the rod D. The form of the burner itself may be varied in any way. The woodcut represents that in which the experimental lamp was constructed.

The burners calculated for lamps exposed to wind, such as those in the public streets, etc., and used without a chimney, are various in shape and size; they are known by the names of the bat's-wing, fish-tail, single jet, or cock's-spur, double and treble jet, star, fan, and Scotch burners. The first of these are usually employed in street-lamps; for the quantity of gas consumed they give the least light of any, but seem to be very well adapted to their purpose. The "cut," or narrow opening from which the gas issues, can readily be cleared by a piece of watch-spring, an advantage, when a number must necessarily be attended to by one man during a short space of time. The quantity of gas they consume varies from two and a half to six feet per hour. The nipples should be case-hardened after they are finished, in order to prevent the cut from opening.

The other burners mentioned are of little importance, and need not be more particularly described.

To regulate the altitude of the flame from the burners, Messrs. Clegg and Crosley, in 1817, applied a small governor to the outlet-pipe of the gas-meter. It is useful in many cases where the number of lights varies; for if the opening of the supply-pipe remains the same under the different circumstances, either a waste of gas is occasioned by the flames being unnecessarily high, or each lamp has to be turned down by hand, which is often very inconvenient. The construction of this consumer's governor is upon the same principle as the large station-governor, but is varied slightly in form, the floating vessel being entirely enclosed in a case, and the cone guided at the bottom. Mr. Clegg's new meter effects this regulation of the flame, being a governor as well as a measurer.

A patent has been taken out for an ingenious instrument to answer the same purpose by Mr. J. Milne of Edinburgh, which he calls a "gas-regulator." The advantage gained by the use of these instruments more than compensates for the small additional expense incurred in fixing them. In cotton-mills and other manufactories consisting of several floors, the regulator will be found of great advantage in equalizing the pressure or supply of gas to each floor, according to the quantity of light required. It is a very general complaint in cotton-mills that the light in the under floor is deficient, while at the upper floors there is a greater supply of gas than is necessary. This inconvenience arises from the upper stories being subject to less atmospheric pressure than the under one, every additional rise of ten feet

making a difference on the pressure of about one-tenth of an inch. Suppose a mill of six floors is supplied from the gas-mains at a pressure of six-tenths, and that the difference of altitude between the highest and lowest lights is equal to fifty feet, the gas in the highest or sixth floor will issue from the burners at a pressure of eleven-tenths, the fifth floor at ten-tenths, the fourth at nine-tenths, and so on. In order to gain full advantage from the regulator, one should be placed on each floor; and in this manner one placed at the top or sixth floor, and adjusted to six-tenths of an inch pressure, will send the surplus pressure of five-tenths to the floor below; another placed on the fifth floor, also set to six-tenths, will send the surplus of four-tenths down to the fourth floor; a regulator on the fourth floor will send the surplus three-tenths to the third floor, from which the surplus two-tenths will be sent to the second floor; between that floor and the ground, the fall being ten feet, the remaining surplus of one-tenth is lost, and thus a uniform pressure of six-tenths will be established over the whole building; and to prevent any inequality from outward pressure, a regulator ought to be placed on the ground-floor also. The gas companies are frequently obliged to supply mills at a much greater pressure than is above stated as necessary, in order that the ground-floor may have sufficient light; it is in such cases that the advantage in point of economy to be derived from using these instruments will be most decidedly experienced.

Many cotton-mills are provided with a check-cock on each floor to reduce the pressure in the pipes of supply; this, if strictly attended to, will prevent an improvident waste of gas as long as the pressure remains the same; but whenever any other mills or consumers supplied from the same street-main light up *after* the mills in question, or stop *sooner*, the pressure will be respectively lessened or increased; and unless the cocks are altered at each change, either a deficiency of light or an excess of pressure, and consequently an extra consumption of gas, will invariably follow.

In providing the means for consuming gas perfectly, we must not forget to provide those for carrying away the products of combustion, especially from close rooms. Every burner consuming five cubic feet of gas per hour spoils as much air as two full-grown men; it is therefore evident that the air of such a room would soon become deteriorated if an ample supply of fresh air be not admitted. But the consumption of atmospheric oxygen by a gas-burner is the least evil: the chief product of combustion is carbonic acid gas, which is incapable of supporting animal life, and if it were not carried away, would soon occupy the place of the oxygen, and the occupants be unable to breathe.

Mr. Rutter in 1843 contrived a ventilating lamp, which he has since introduced extensively, and has found it to act well. It is represented in Fig. 42[a]. A is the pipe supplying gas to the burner B. C is the chimney-glass. D is a tube or chimney for conveying away the products of combustion. E is a glass globe enclosing the light, and open only at the top, where air enters for the supply of the burner. The arrows, *a*, *b*, *c*, show the direction of the air-currents.

Fig. 42[a].

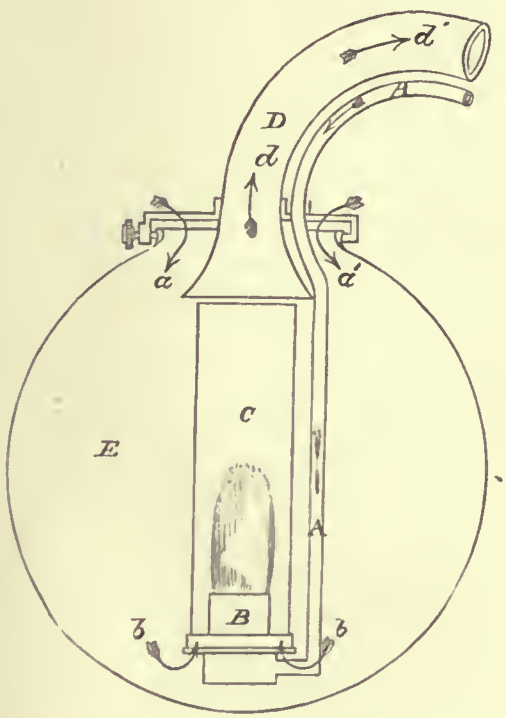


Fig. 42[b].

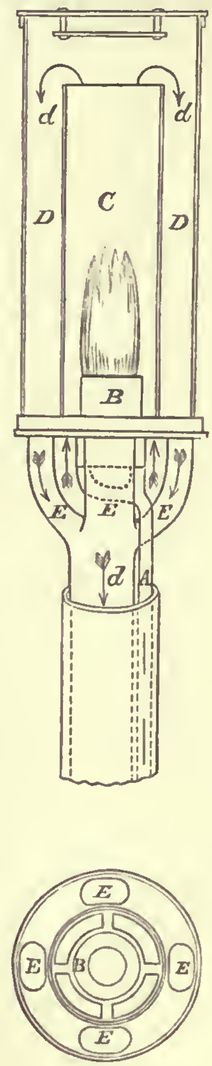


Fig. 42[b] represents the ventilating standard lamps used in the House of Lords,

contrived by Mr. Faraday. B is the burner; C the chimney-glass; D D an outer glass, through which the vitiated air passes away through the pipe E communicating with the external air. The arrows *d* denote the direction of the air-currents. The cover of the outer glass D is of mica.

Mr. Rutter in 1846 published a little book called 'Practical Observations on the Ventilation of Gas-lights,' and I cannot do better than refer my readers to it; it is full of information, which all who are acquainted with this gentleman's writings will readily believe.

APPENDIX.

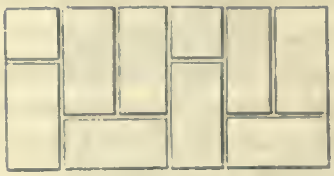
The dimensions of ordinary bricks (10 inches long, 5 inches wide, and 3 inches deep) vary according to the amount of contraction that takes place during the drying and burning. The average size may be taken at $8\frac{3}{4}$ to 9 inches long, $4\frac{1}{4}$ to $4\frac{3}{8}$ inches wide, and $2\frac{1}{2}$ inches deep. The depth of a brick need not bear any definite proportion to its length and breadth, but the length must exceed twice the breadth by the thickness of a mortar joint—viz. about $\frac{1}{4}$ inch.

The necessary qualities of good bricks are, that they should be true in their shape, and ring when struck together; because the absence of the first prevents the possibility of good work being executed with them, and of the last shows that they have not been sufficiently burned. The colour of a brick is no index of its quality. Bricks of a uniform colour add to the good effect of work, and therefore should be chosen; but this uniformity may be of any shade. Truly shaped and sound *stocks* are the most generally serviceable for engineering work; *place* bricks are those which have not been thoroughly burned, and are worthless.

When bricks are placed together, and united by mortar or cement, so as to form walls, piers, or any other erection, it is called *brickwork.* The strength of a mass of brickwork, in any form or situation, depends more upon the proper arrangement of the materials forming it, than upon the strength of the materials themselves, if they are at all fit for the purpose of building,—that is, if they will not crush with the weight of the mass above them, and will resist weather.

When two contiguous bricks have a third lying over or against them, so as to cover the joint between them, they form a certain dimension of overlap, and unite their strength, one brick being difficult to remove without the others; this is called *bond,* and the amount of overlap is the amount of bond; thus from *a* to *b* (Fig. 1) is half-bond, the overlap being $4\frac{1}{2}$ inches, or half the length of a brick; from *c* to *d* is quarter-bond, the overlap being one-quarter the length of a brick, or $2\frac{1}{4}$ inches. *Stretching* bond is when the longitudinal direction of the bricks is parallel to the face of the wall, and consequently presents the whole length of the bricks on the outside. Thus the course *f* is a stretching course, and the bricks of that row are called *stretchers.* *Heading* bond is when the longitudinal

Fig. 3.



the facework alternately of brick and half-brick in thickness. This, as far as relates to the *splitting* of the wall, is an effectual preventive; but in curing one evil another is increased, for there is no stretching bond to bind the work together longitudinally, the little that occurs in Flemish bond being too trifling to avail much.

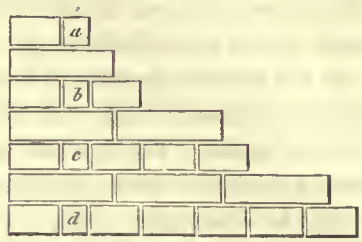
There is yet another practical reason why Flemish bond is objectionable. When the Flemish facings occur on both sides of the wall, they furnish no indication of the interior arrangement, they supply no guide to the workman as to the disposition of the vertical joints, for every course is similar on the outside. The interior of the top course is not seen, on account of being covered with mortar for the bed of the next course above it; and to recollect how every brick was laid beneath, is more than can be expected from men who are despatching work. The work will, by inadvertence, produce continued joints that divide the wall into several thicknesses, when the separation or splitting usually takes place. In the old English bond, a workman cannot lose his way, for the outside of the last course shows him how the next is to be laid. It may be observed, that in the same course there cannot be *both* heading and stretching bond with complete effect throughout the line of wall, for wherever the stretching bond is crossed by the heading bond, the continuity and effect of stretching bond is destroyed; therefore the mixed position of the bricks will not answer, and it often produces a perpendicular joint in the middle of the thickness, dividing the length effectually into two or more walls. The outside appearance is all that the most strenuous advocates for Flemish bond can advance in its favour: on this however opinions are far from being in accord. Thus much has been said about Flemish bond, that it may be avoided.

The directions for laying English bond to be given in specifications are—each course to be alternately all headers and all stretchers; *every brick in the same course is to be laid in the same parallel direction*, and in no case is a brick to be placed with its whole length alongside of another, but to be so situated that the end of one may reach to the middle of the others that lie contiguous to it, except in the outside of the heading courses, when *closer* bricks necessarily occur at the ends to prevent a continued upright joint in the face-work; quoins, or walls that cross at right angles, will have all the bricks of the same level course in the same parallel direction, which completely bonds the angles. These directions answer for walls of all thicknesses, all that is necessary being to repeat the courses until the proper thickness is attained.

Bricks on the same course have half-bond with one another, while the bricks of the upper and lower courses have only quarter-bond with those above or below them; this is obtained by inserting *closer* bricks at the ends of each heading course, and these may be quarter bricks or three-quarter bricks; the first are termed *queen*, and the second *king*, closers. Upon the nicety with which these closers are adjusted depends the bond of the entire work; and to make sure of the closers being thus properly adjusted, the best work-

men only should be employed to raise the quoins, which consist of a certain number of courses racked back above the intermediate portion, as in Fig. 4. The quoins give also *line* to the work. The closers *a, b, c, d,* are the bricks that give the longitudinal bond, by causing the second header of the course to lie half-way over the joint between the first and second stretcher, which it would not do if no closer were inserted. The angle or quoin of the wall is made perfectly vertical (or plumb) by a plumb-rule, and the courses are worked by a gauge-rod, which is a rod marked into courses occupying the space specified—viz. 4 to 11, 11½, or 12 inches. These quoins are elevated at each end of the wall, or, if the wall be very long, at distances apart varying from 30 feet to 40 feet; a line is then stretched on the first horizontal joint between the two quoins, to which the bricklayers work, and make the line of each course perfectly horizontal.

Fig. 4.



The vertical range of closer bricks are technically called *perpends,* and in specifications it is frequently thought advisable to direct that "the perpends are to be truly kept;" for when they are not, the longitudinal bond cannot be perfect. With every care, it is always requisite to be watchful, for bricks are not exactly of the same length—they may overrun or underrun their position in bond; the vertical joints may also vary a little in thickness, therefore a three-quarter or a cut brick has often to be inserted to gain anything that has been lost, or to keep back joints that have overrun. If the face and flank of a wall be not at right angles, the quoin becomes externally a "squint," and internally a "bird's mouth" or "splay," for both of which bricks have to be cut.

In building what is termed "compass" work—that is, work circular in plan—raised quoins would be useless, as the line would form a chord to the arc of the wall, and could not be worked to; therefore the workman has to use his gauge-rod constantly to get his courses, and a trammel or template for the sweep of the wall. For circular work of small radius, "compass" bricks, moulded to the curve, are used.

The mortar-joints for the beds, ends, and sides of bricks should be laid on with the trowel carefully; to use technical language, "the work must be flushed-up solid with mortar." The general way of laying mortar is to spread the bed, scrape off with the trowel that which exudes from the face-joint when the brick is pressed into its place, and then wipe the trowel against the face-edge of the brick, leaving the remaining joints to be filled in with the mortar that is spread for the next bed, or with *grout,* which is mortar made so thin as to run into the joints. I believe grouting to be utterly worthless, and that there is no substitute for flushing-up. When carrying up work, do not allow one portion to be raised above another more than three or four feet, as the weight upon the joints of any portion so raised will condense them more than those in the lower parts, which should be avoided;—not that the compression amounts to much in moderate work,

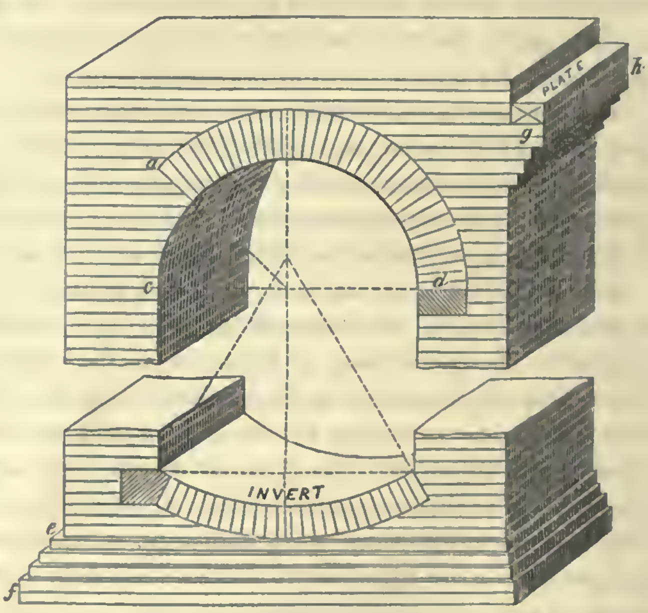
but the principle should be carried out. If high chimney-shafts have to be built alongside of ordinary walls, they must not be bonded with the wall, but left to settle independently. If high buildings are bonded with lower ones, it is prudent to allow the work to settle for some days at one uniform height before carrying up the rest.

It is a common practice to leave toothings in the ends of walls, if it is the intention at any future time to erect walls in continuation of them, as will be observed in unfinished rows of houses. This is a bad practice, for the settlement of the green work will almost always break the bricks placed in the toothings of the old work. Junctions by indent should be substituted, which is a half-brick groove left in the end of the wall from top to bottom; the new work projected into this groove will settle without damage.

"Voids must be over voids"—that is, all openings in walls must be over one another, so that the piers which separate them may be carried up of a uniform width from the foundation; if this were not the case, the bases of the upper piers would be over voids, or partially so, causing certain inequality in the settlement of the work.

Beneath voids, or beneath thinner work between piers, inverted arches, or "inverts," should be turned, as in Fig. 5, so that the pressure may be distributed equally over the foundation, and also that the settlement of the piers may be identical with that of the thinner work. It is a good custom to build these inverts in cement. The radius of curvature is usually equal to the width of the opening—*i. e.* the chord and two radii forming an isosceles triangle, as in the figure.

Fig. 5.



In turning an arch between two piers, or over an opening, above which weight is imposed, the skew-backs, or springing *a b*, Fig. 5, should be formed by corbelling out the courses of brickwork from the line *c d*, so that the back of the arch may be disengaged from the internal upright of the wall. This is a custom not much followed, but it would be well if it were. The usual method is to spring the arch from *d*; but the pier above it has then a wedge-shaped base, which is not calculated to resist all the pressure due to the area of the work. When any stone, as at *d*, is bedded in a wall, the courses at the back should be set in cement, to prevent unequal settlement.

To give the bottom of a wall greater spread or surface in contact with its foundation, footings are provided, as at *e f*, Figs. 5 and 6. Each course should not project more than quarter-brick beyond that above it. The bases of all walls must be at right angles with their faces, and the joints carried up parallel to them. In "battering" walls, or those whose faces lean from the vertical, this must be carefully followed, to prevent any tendency in the joints to slide. The amount of batter in Fig. 6 is one in ten, which means 1 foot horizontal to 10 feet vertical; but this ratio may vary according to circumstances. The strength of a wall to resist horizontal or inclined pressure depends upon its base, other dimensions being constant; if therefore counterforts or buttresses are built at intervals against a wall, as in Fig. 6, great additional stability may be attained with comparatively little additional material. In the notes on "Retaining Walls," a practical rule will be given for the dimensions of battering walls and counterforts.

When a timber plate has to be bedded, it must never be placed within the substance of a wall, as by decaying it will cause the superincumbent brickwork to settle; but they should be laid on "salient courses," corbelled out to the proper projection, as in *g h*, Fig. 5; these courses should be all headers in cement, the remaining thickness of the wall being also in cement. Two courses of bricks in cement, corbelled out 4½ inches, as in the sketch, will give way under a load of 24 cwt. per foot run; safe load stated to be 12 cwt. per foot run*. To give bond to work beyond that possible to be got by the mere overlapping of the bricks, hoop-iron along three or four courses should be laid in at intervals of from 10 feet to 15 feet in height; and if, in addition, these courses are set in cement, the "string" bond will be more perfect.

To span openings which require to have a straight soffit, as in house-building, the flat arch is employed, as in Fig. 7, which is a beam of brickwork formed with bricks radiating to a centre, so that it may contain an arch of 9-inch work. It is too often the practice to build false arches for this purpose, as in Fig. 8, which, having no key, do not possess any of the properties of the arch, and are worthless; if they stand, their stability is due to the adhesion of the mortar.

Fig. 6.

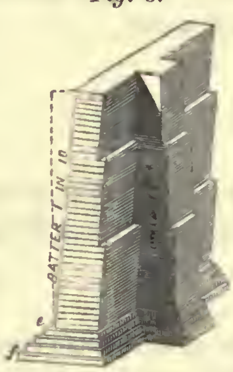


Fig. 7.

Fig. 8.

The pressure that *good* bricks will resist is very considerable; well-burnt stocks may be safely entrusted with 20 tons per foot super., but they must be *perfect* bricks. Place bricks will not stand probably more than 2 tons per foot super. I have remarked in a previous chapter that bricks should be *wet* when they are laid, otherwise they will absorb the moisture from the mortar, and prevent its proper induration.

* Professional Papers, Royal Engineers, vol. vi.

As to the quantity of material and labour required for any brickwork. Brickwork of considerable superficial area, and of comparatively little thickness, as in house walls, is measured by the rod of 16½ feet square, making 272 feet super., the thickness being reduced to 1½ brick as a standard. The rod therefore contains 306 cubic feet. Find the area of wall in feet, multiply this by the factor of the thickness; the result, divided by 272, will be the number of rods. The factors are the constant ratios which the number of bricks in the thickness of a wall bear to 1½ brick, and are obtained by dividing that thickness in bricks by 1½. Thus, suppose a wall to be 4 bricks thick, $4 \div 1\frac{1}{2} = 2{\cdot}66$, which is the factor by which the area of the wall is multiplied to reduce it to the standard thickness.

Brickwork in mass, as in bridges, retaining walls, etc., is measured by the cubic yard. The heights, lengths, and thicknesses are taken in feet and inches; these dimensions multiplied together, and divided by 27, will give the contents in cubic yards. A rod of reduced brickwork is equal to 11⅓ cubic yards. A rod of brickwork laid to a 12-inch gauge —*i. e.* four courses to 12 inches high, requires 4350 stock bricks. To a gauge of 11½ inches, 4550 stocks are required. But in buildings containing flues and bond timbers, which are not deducted in measuring, 4300 stocks are sufficient for 1 rod.

One rod of brickwork requires 71 cubic feet of mortar, or 1½ cube yard of chalk lime and 3 loads of sand; or 1 cubic yard of stone lime and 3½ loads of sand; or 36 bushels of cement and an equal quantity of sand. 27 cubic feet of mortar requires 9 bushels of lime and 1 load or 27 cubic feet of sand. One rod of brickwork weighs on an average 15 tons. These quantities divided by 11⅓ will give the quantities of material required for 1 cubic yard. A bricklayer, with the assistance of his labourer, will lay 1000 bricks in ten hours, in straightforward work*.

The following may be taken as the cost for producing every 1000 cubic feet of gas, by an establishment making 365 millions per year:—

Production Account.

Dr.	*s.*	*d.*
To coals, @ 16*s.* per ton (producing 9200 cubic feet per ton) .	1	8·87
To labour, @ 3½*d.* per 1000 cubic feet	0	3·50
To wear and tear of retorts	0	2
To lime	0	0·25
To wear and tear of works and mains	0	2
	2	4·62

* Abridged from an Article by the Author in the 'Architect and Civil Engineer's Journal.'

Cr.	*s.*	*d.*
By surplus coke (after using 20 per cent. for heating retorts), for sale, @ 10*s.* per chaldron	0	10·45
By breeze (8 chaldrons per 100 tons of coals), for sale, @ 4*s.* per chaldron	0	0·42
By tar (being 10 gallons per 1 ton of coals used), for sale, @ 1*d.* per gallon	0	1·08
	0	11·95

Distribution Account.

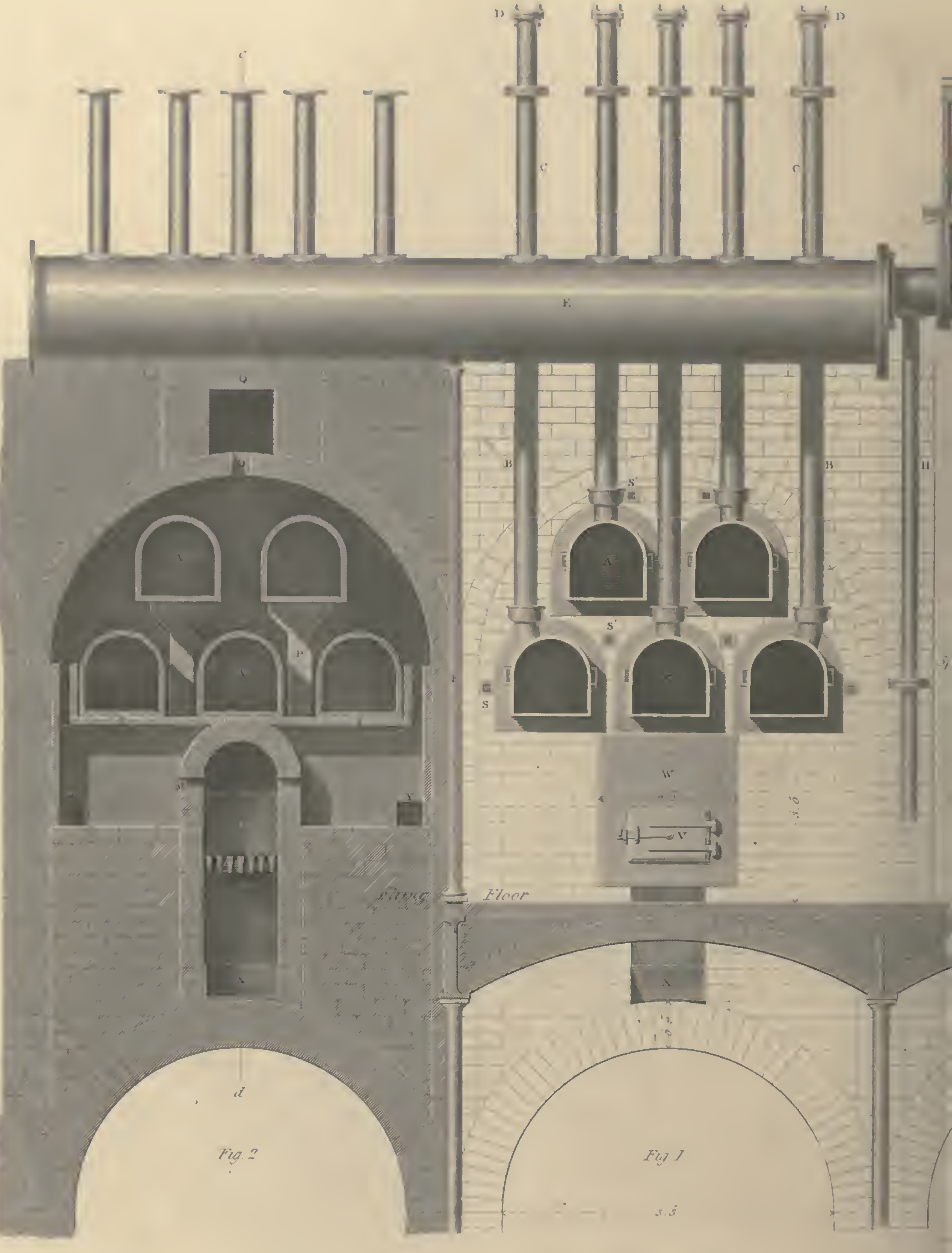
Dr.		
To lighting and repairing of lamps (2678, @ 15*s.*)	0	1·31
To collection and bad debts (2 per cent. on rental)	0	0·80
To rates and taxes (2 per cent. on rental)	0	0·80
To law expenses	0	0·20
To stationery and incidental expenses	0	0·78
To Directors	0	1·30
To engineers, secretary, clerks, and inspectors	0	1·95
To maintenance of works (1 per cent. on capital)	0	1·08
To wear and tear of meters (10 per cent. on value)	0	0·49
	0	8·71

INDEX.

THE END.

JOHN EDWARD TAYLOR, PRINTER, LITTLE QUEEN STREET, LINCOLN'S INN FIELDS.

LIST OF PLATES.



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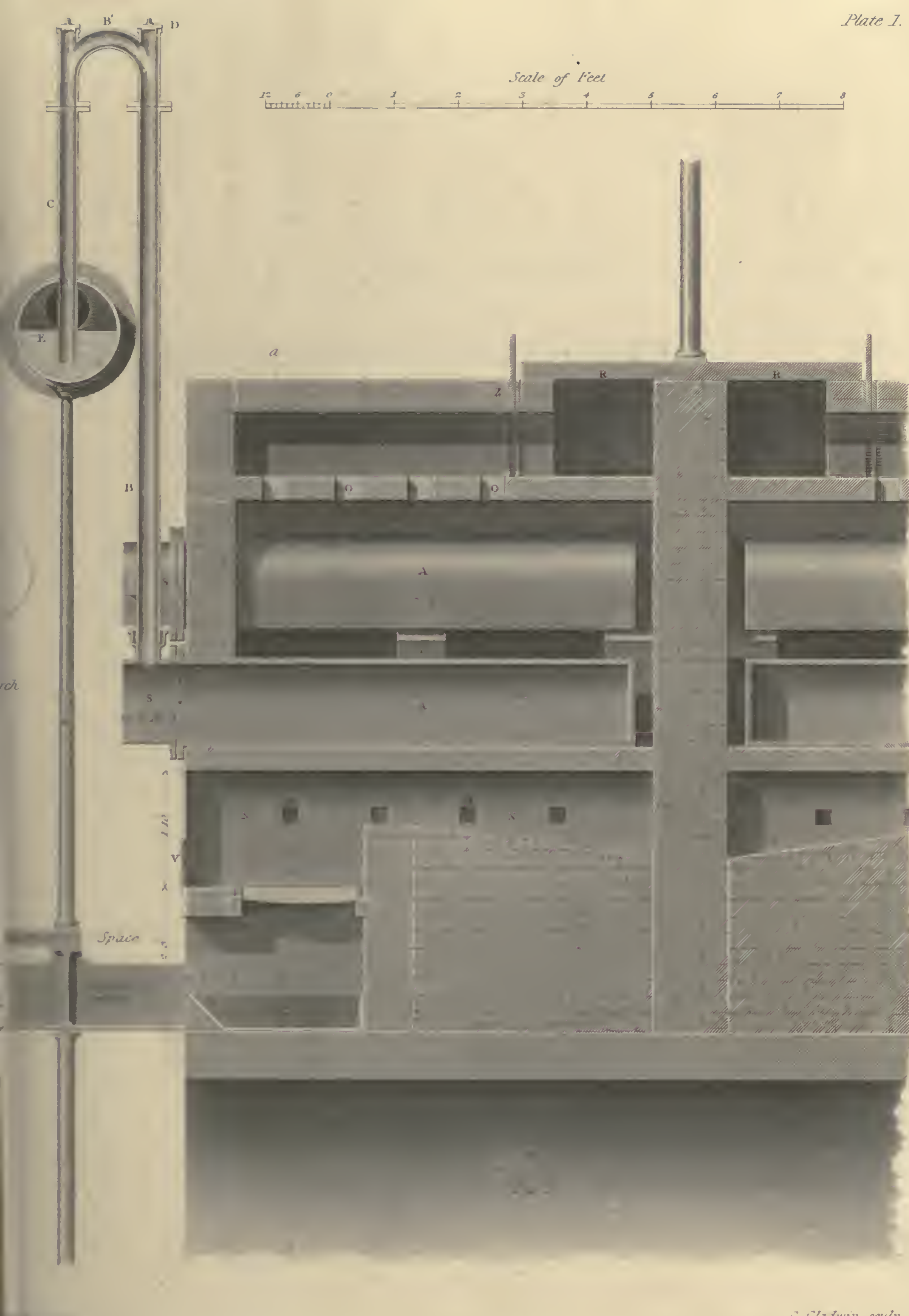

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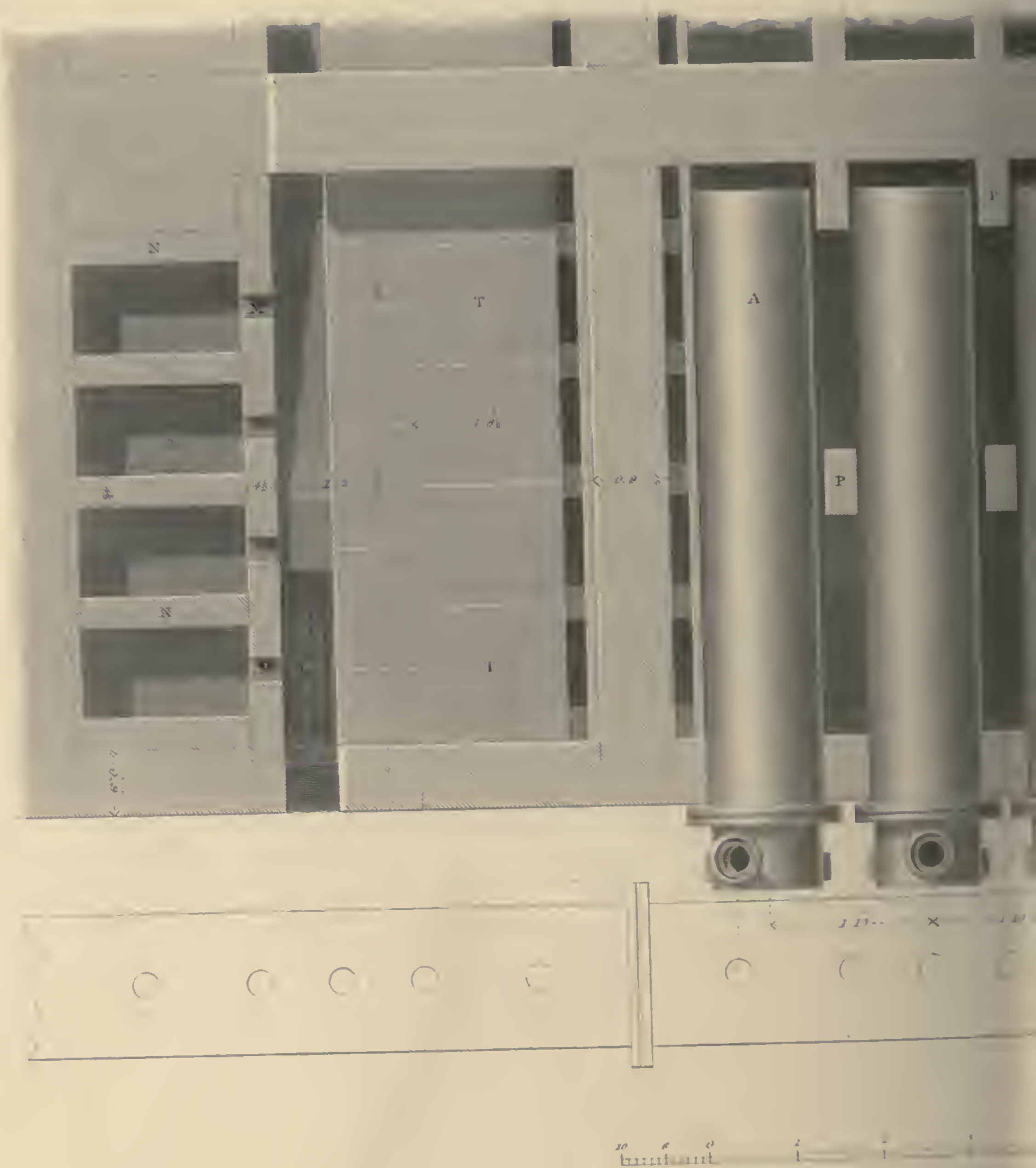

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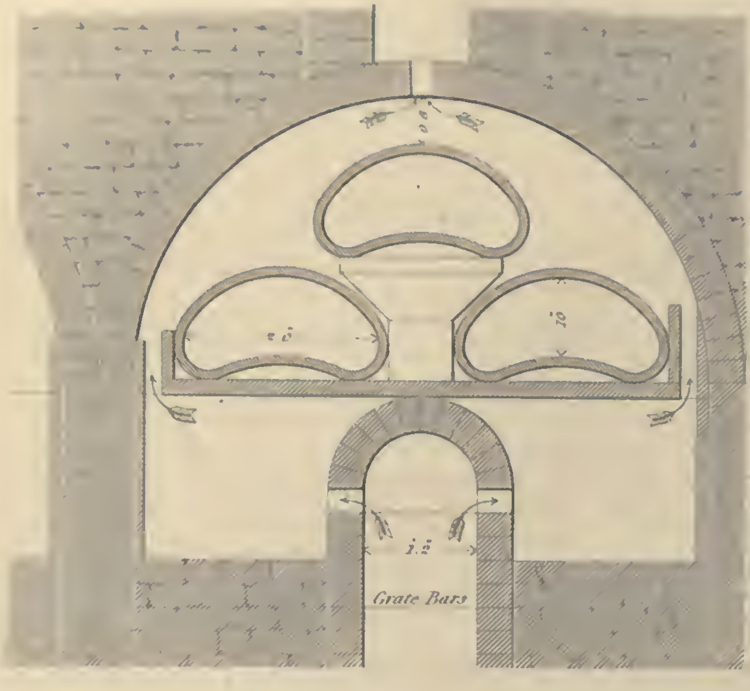
Fig 2



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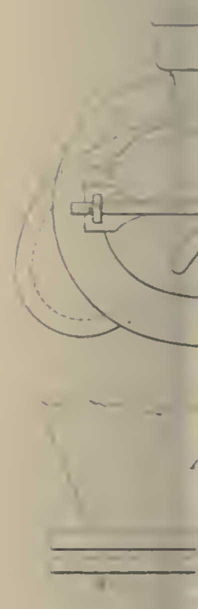

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Plate III.

Fig. 3

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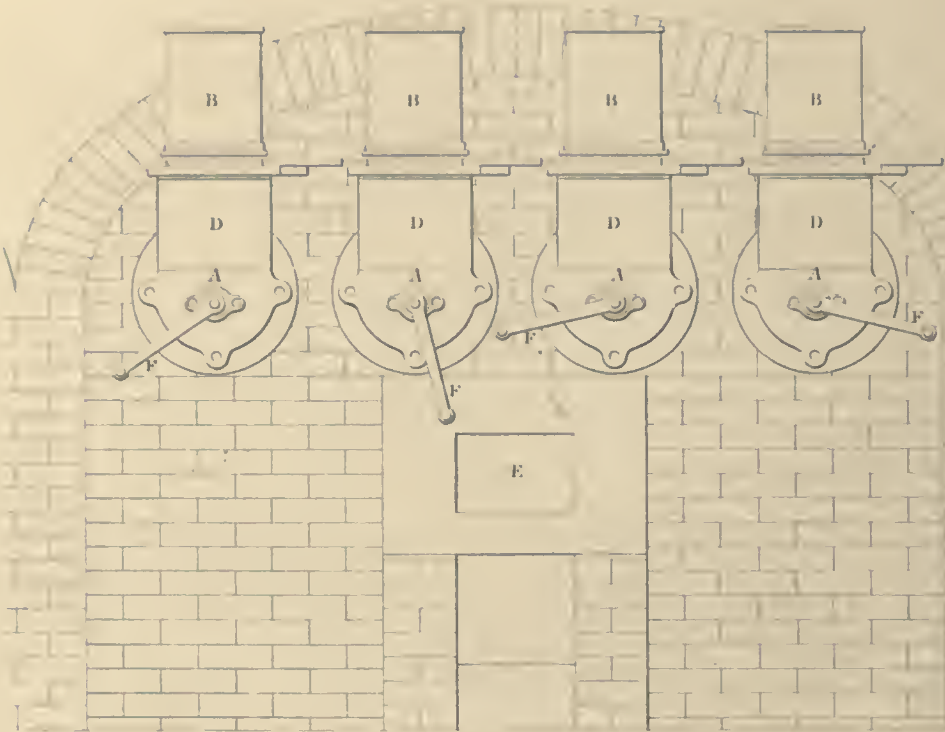
Fig. 1.



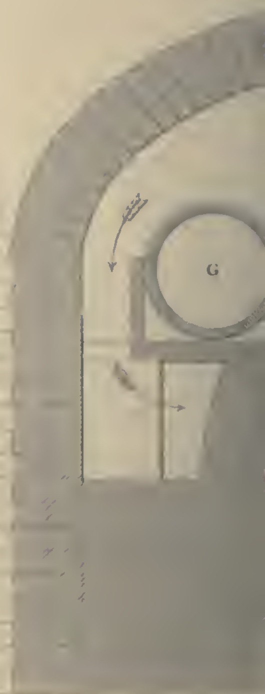


Fig. 4.

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Plate IV.

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Fig. 1

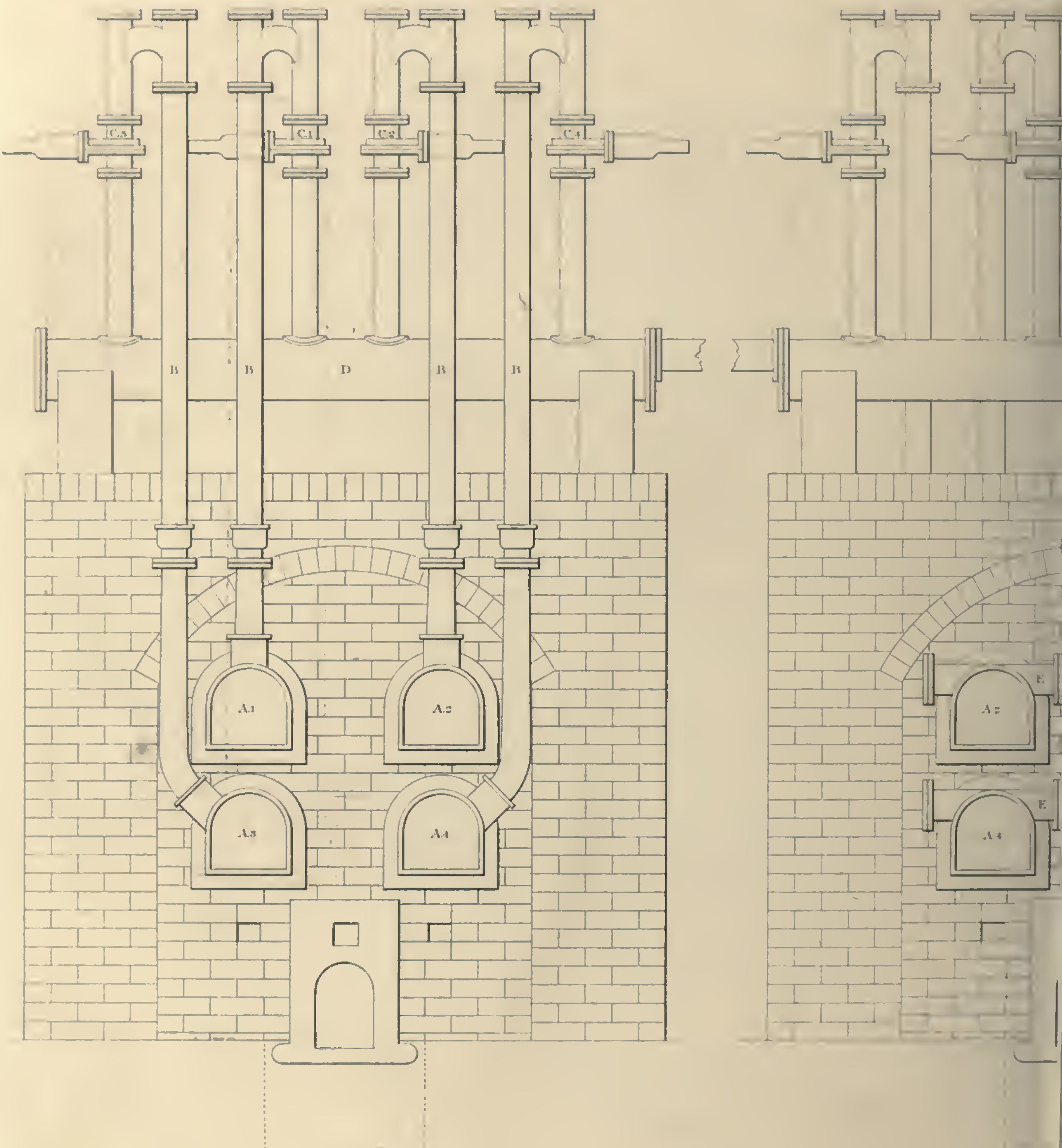

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Plate V

Fig. 3

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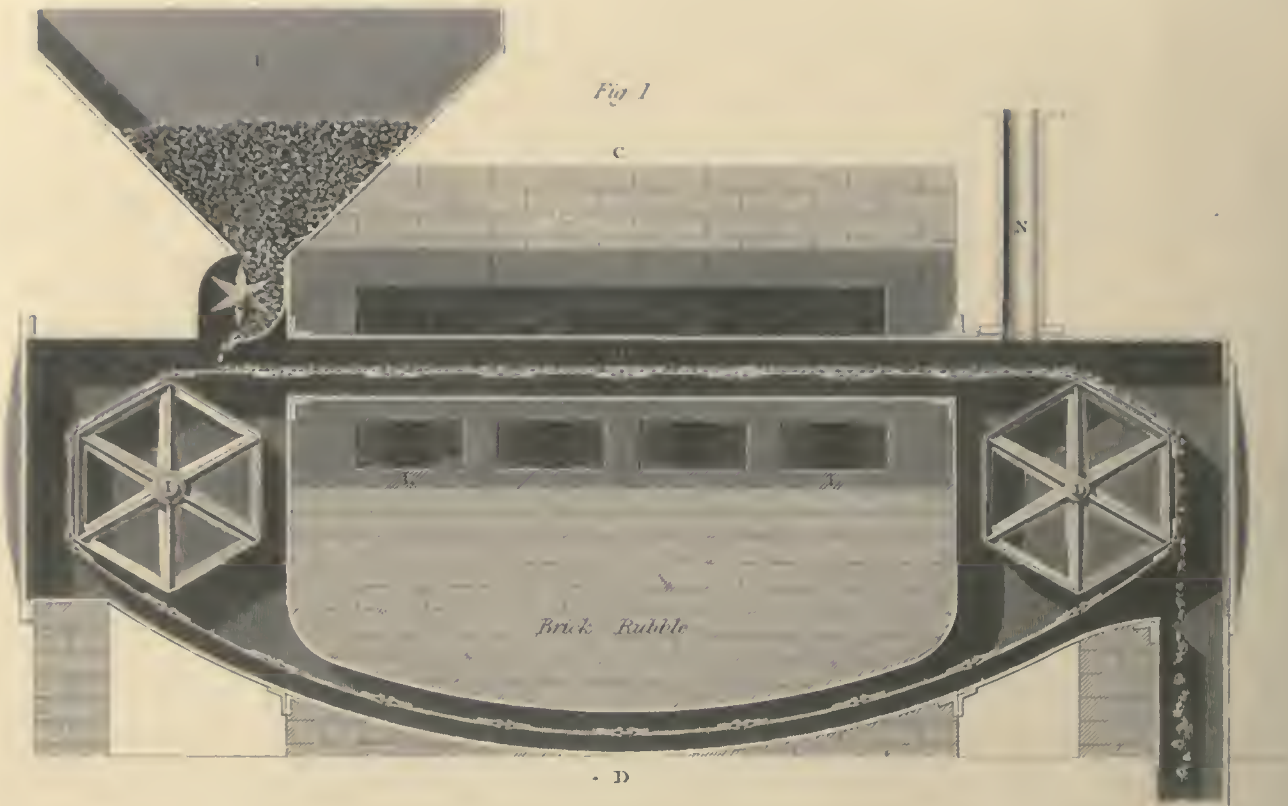

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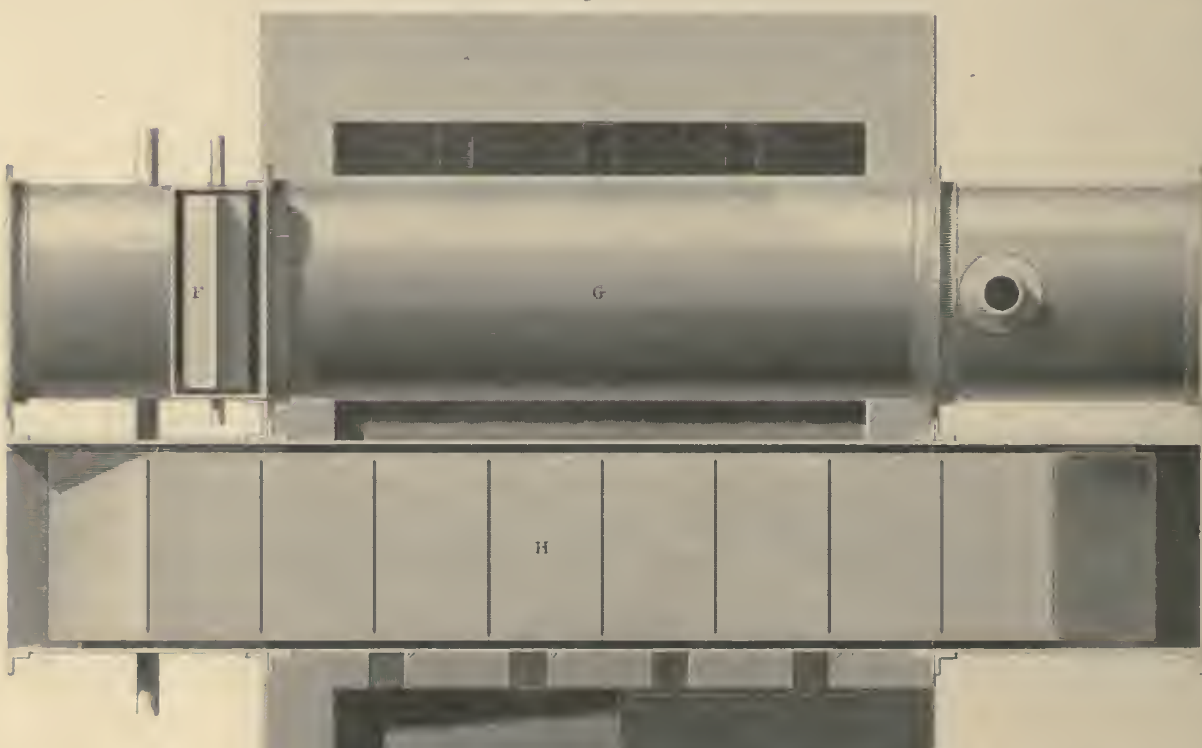

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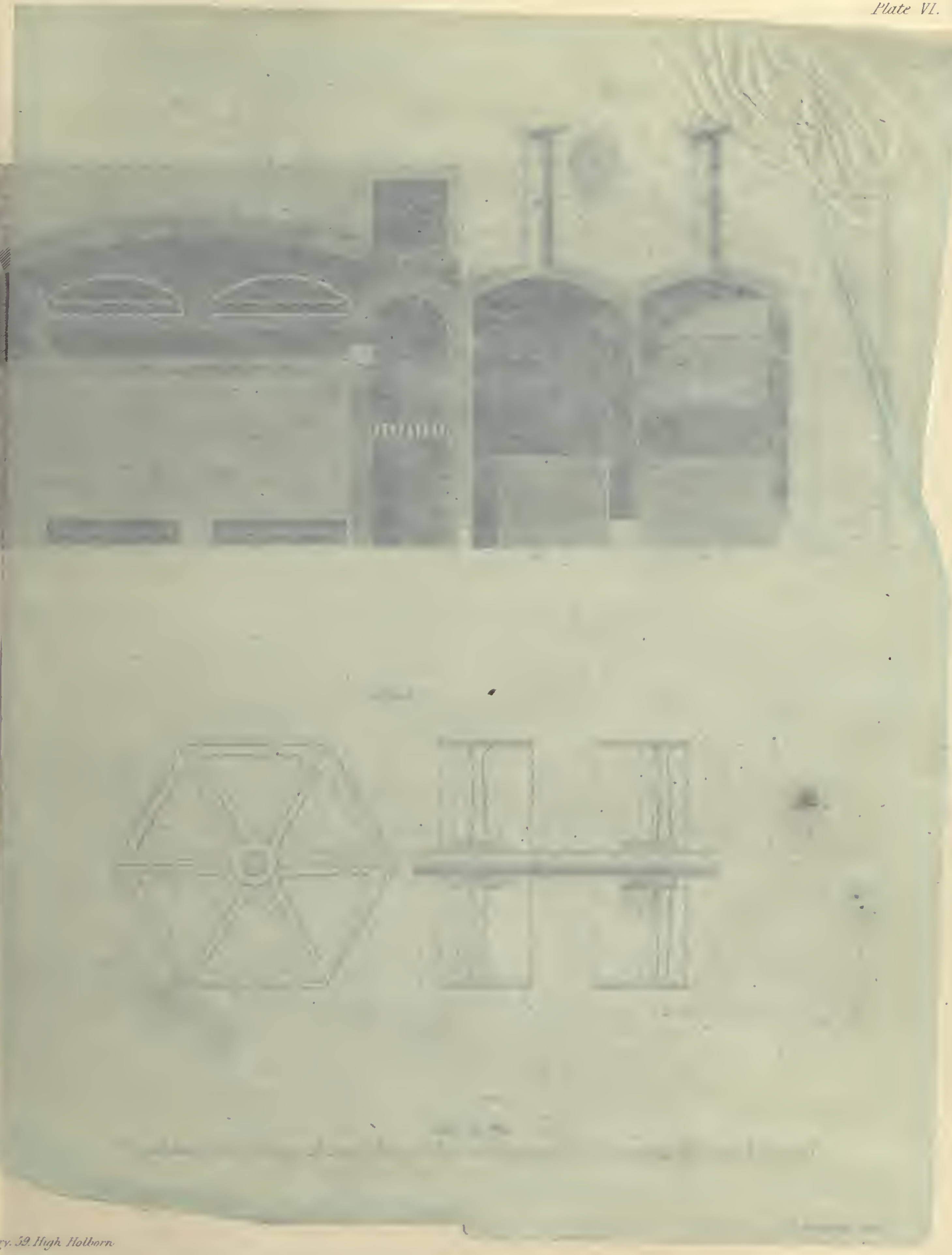

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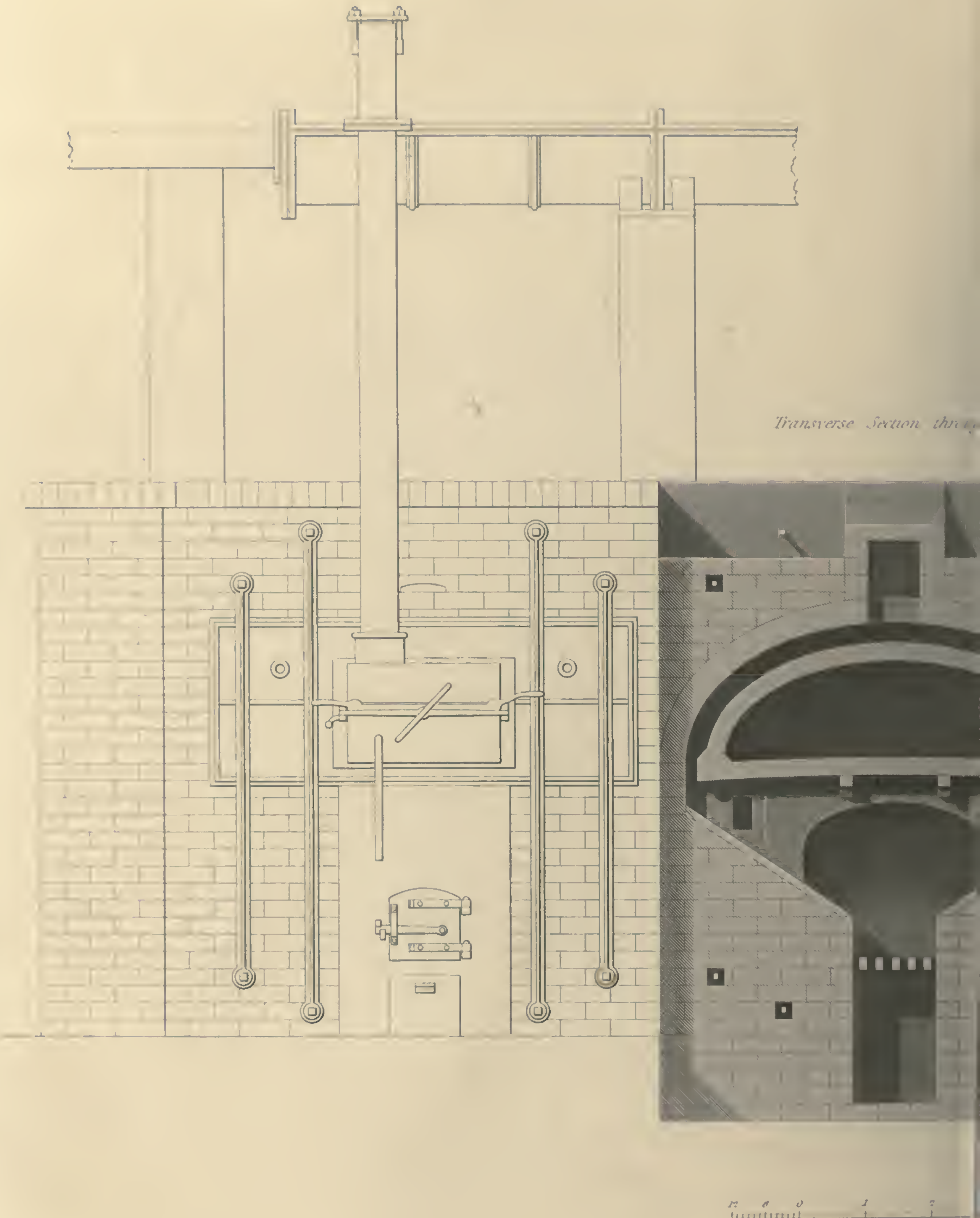

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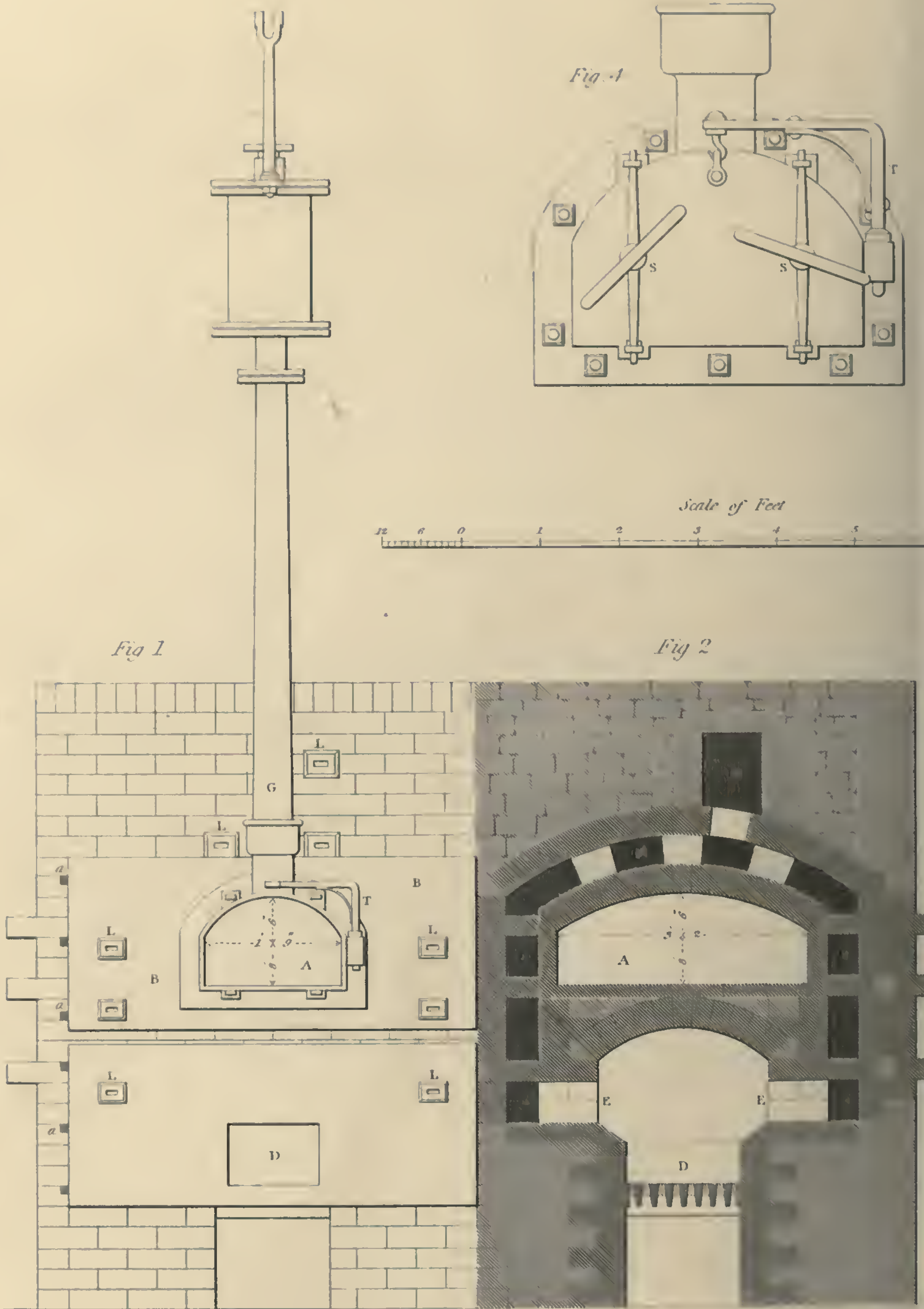

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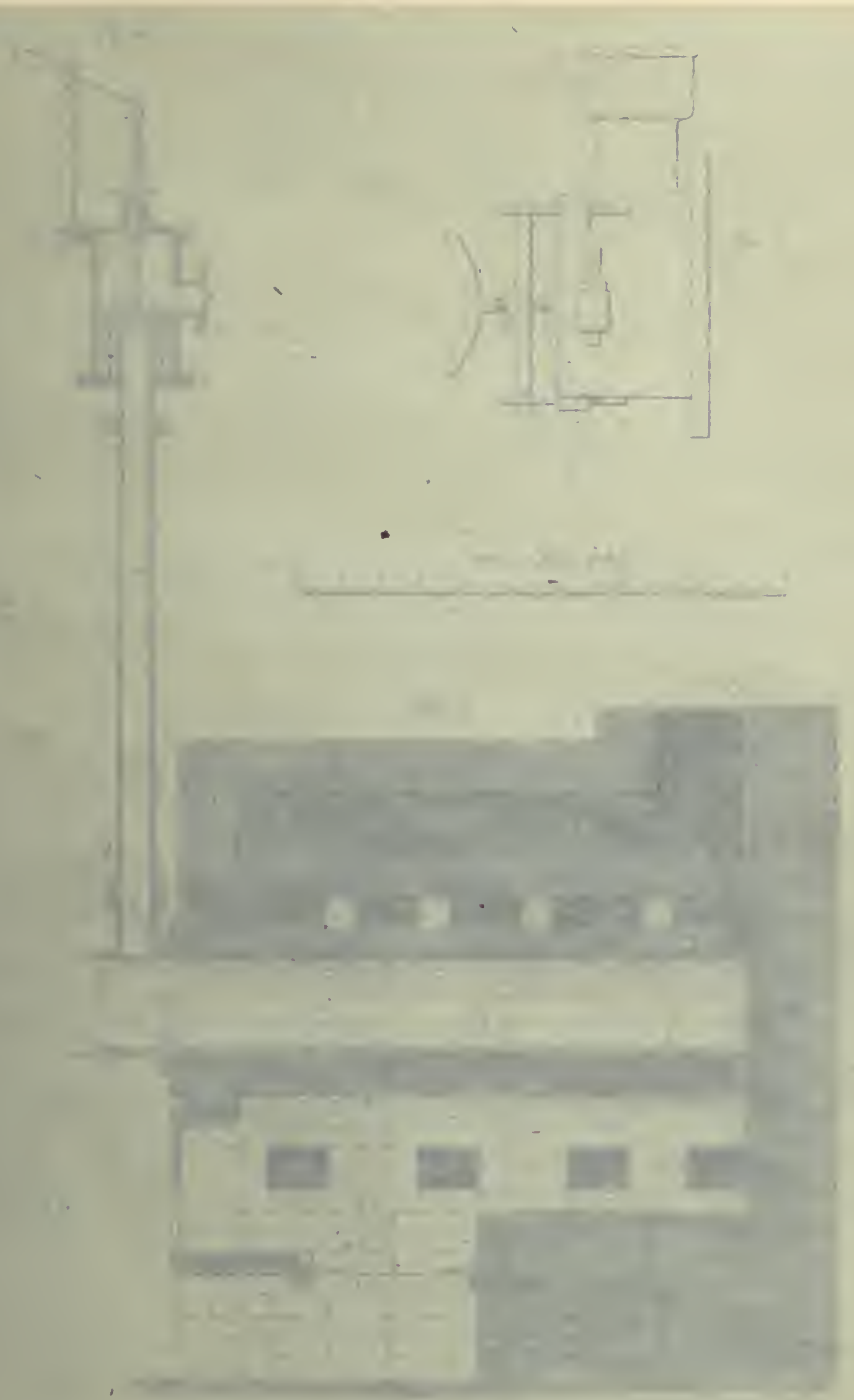

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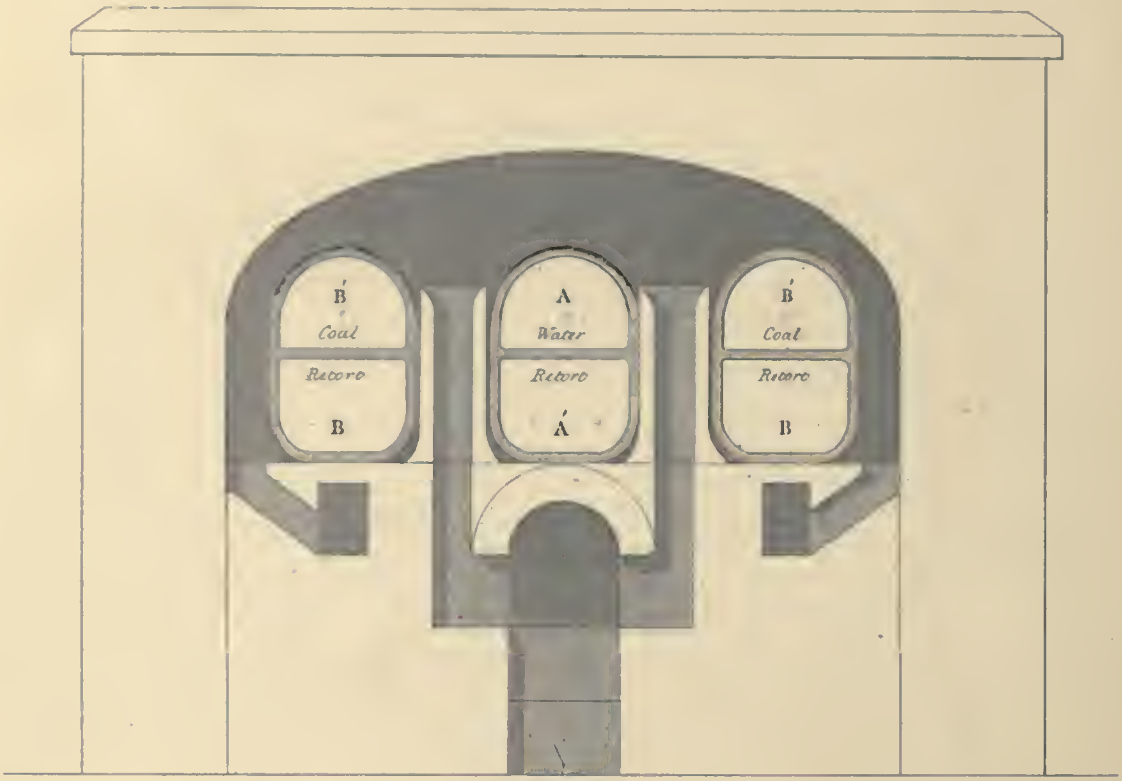

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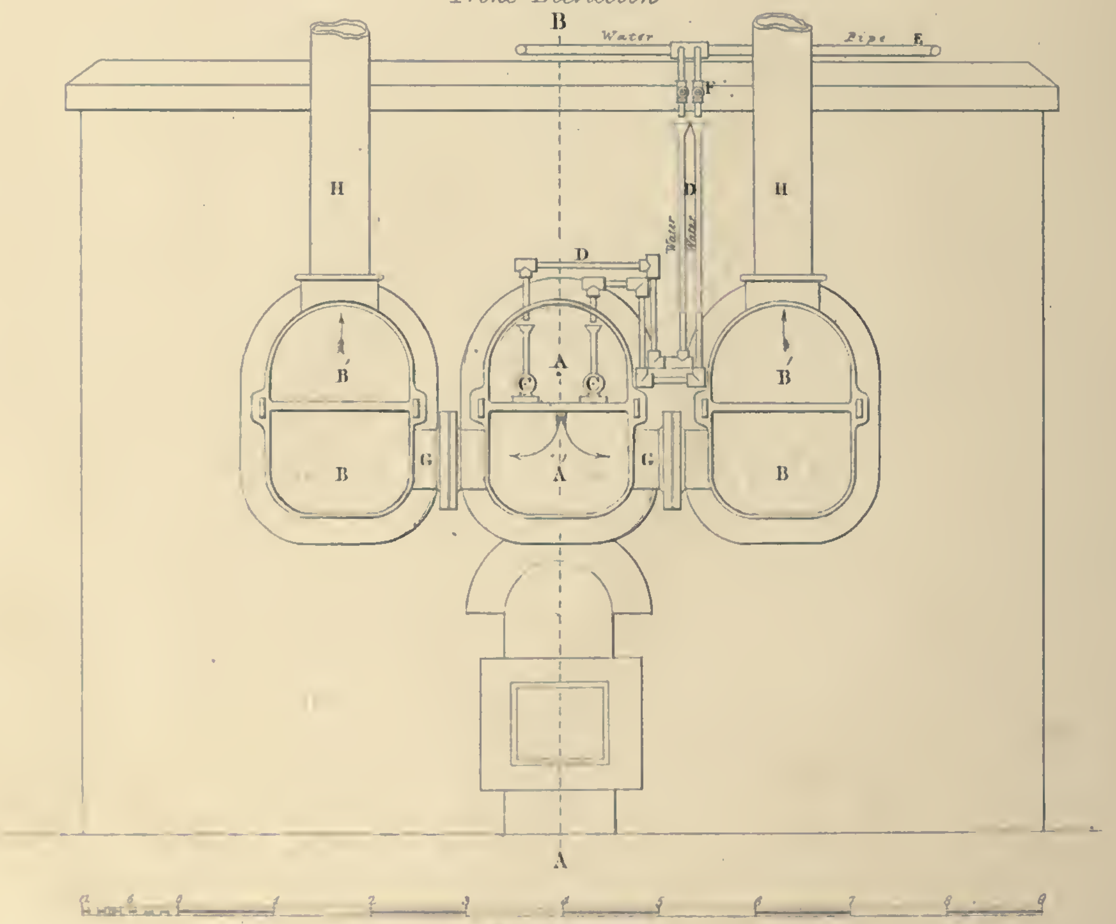
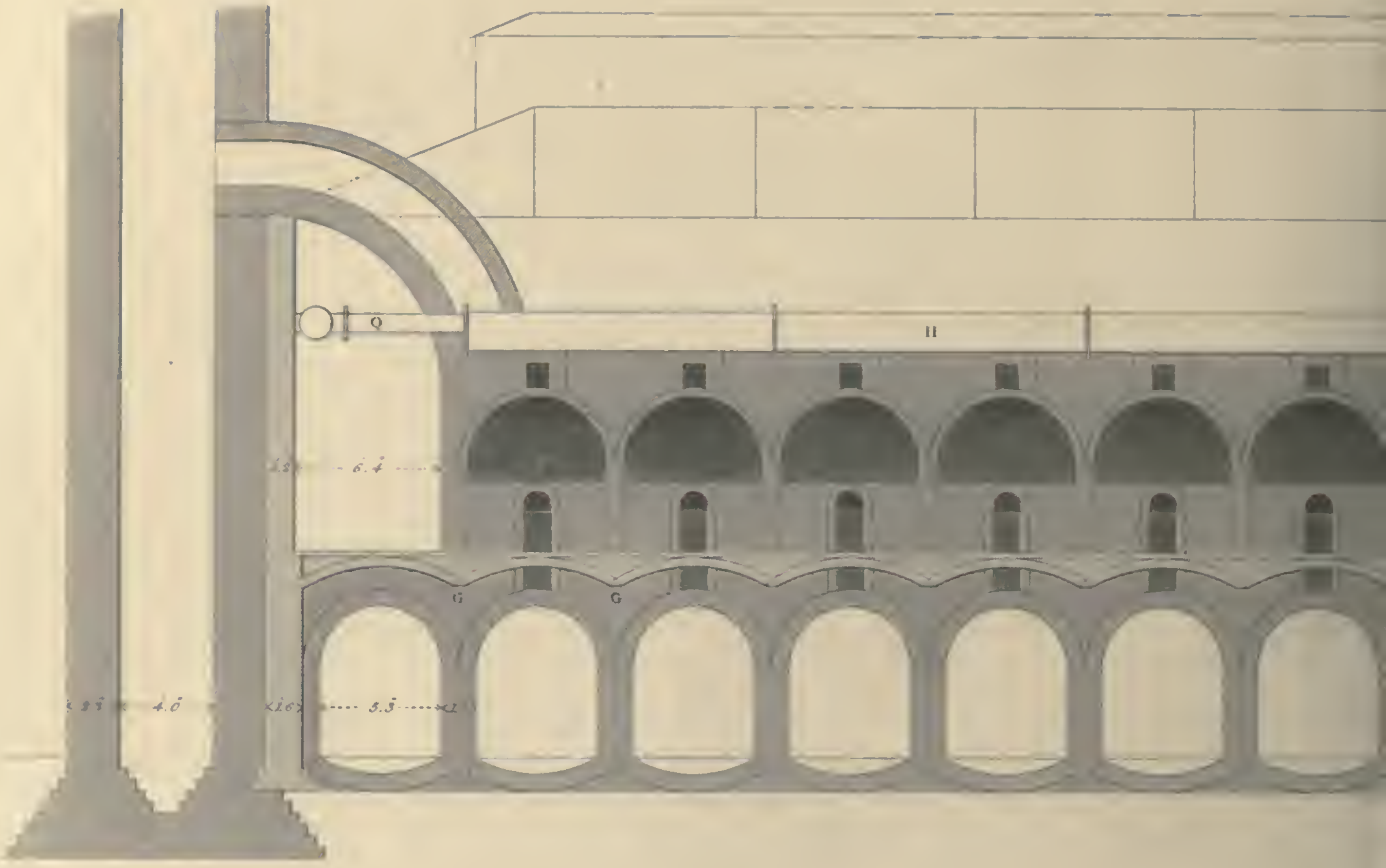


Scale of Feet



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IX.

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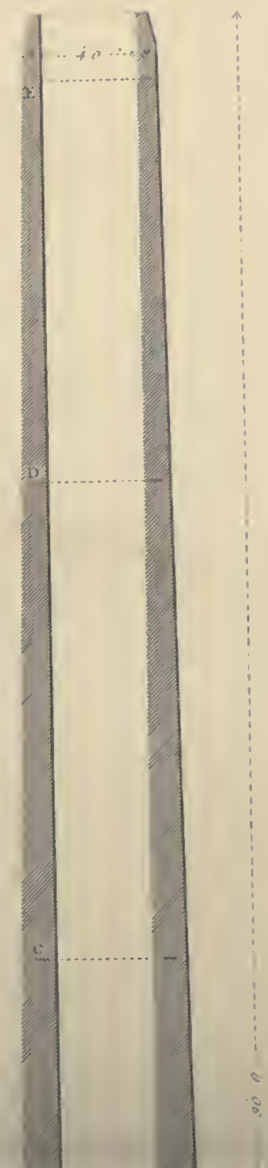

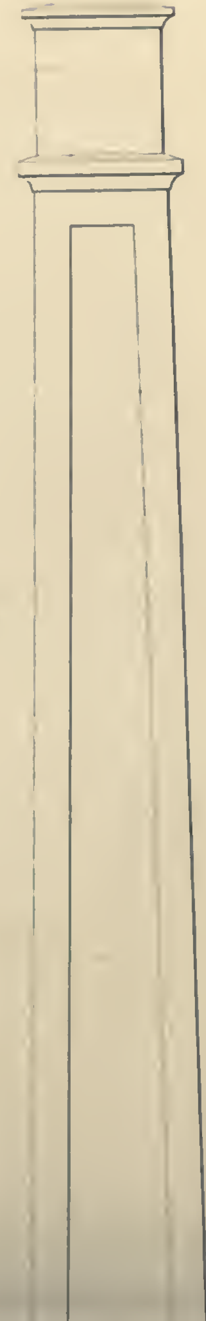

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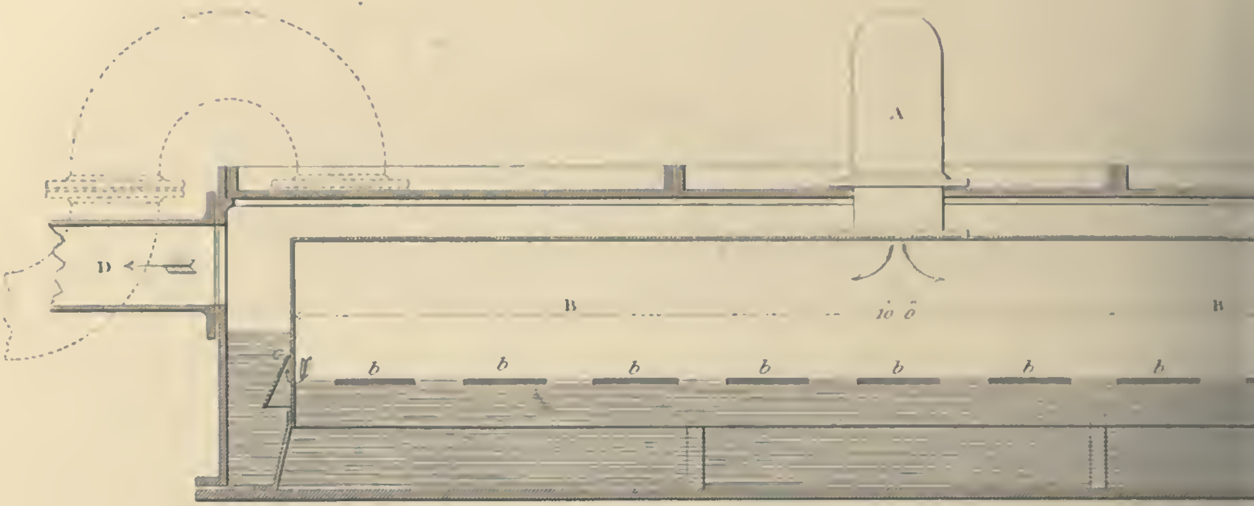
Longitudinal Section



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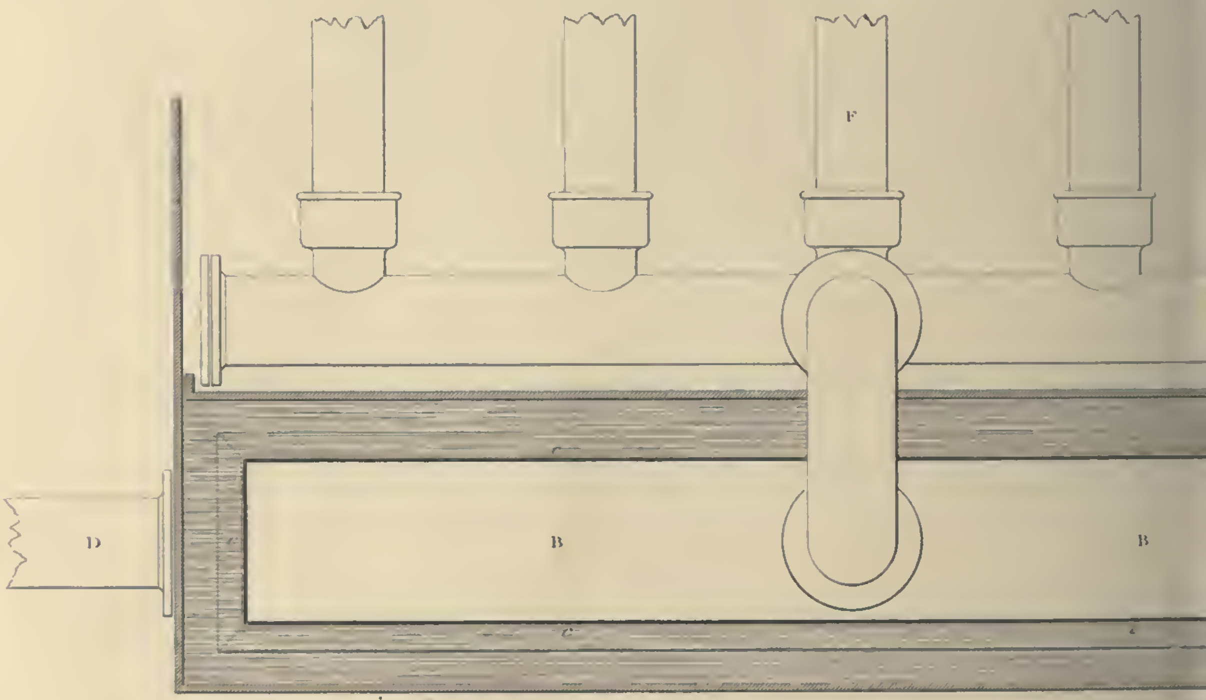

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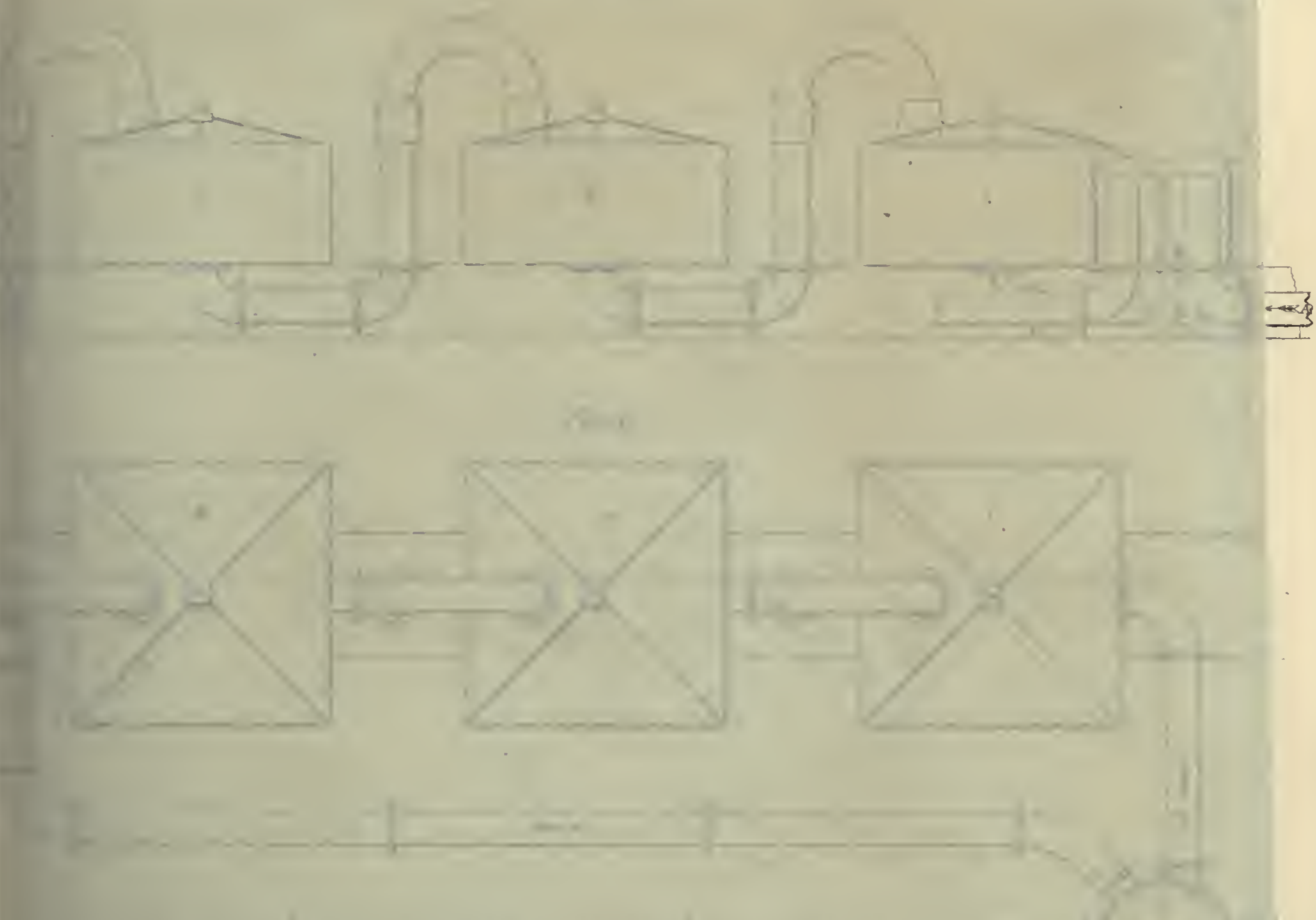

Fig. 1.

Plate XIV.

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Fig. 1

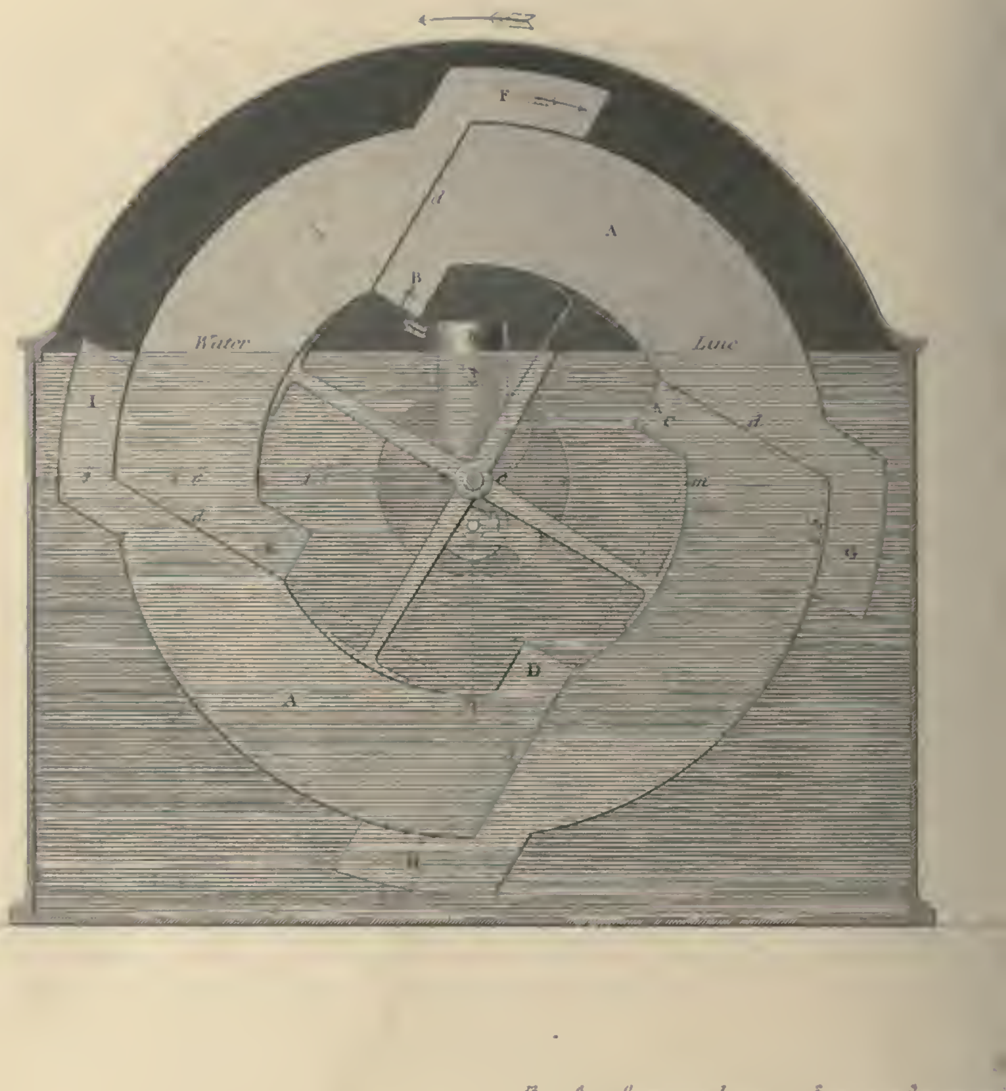

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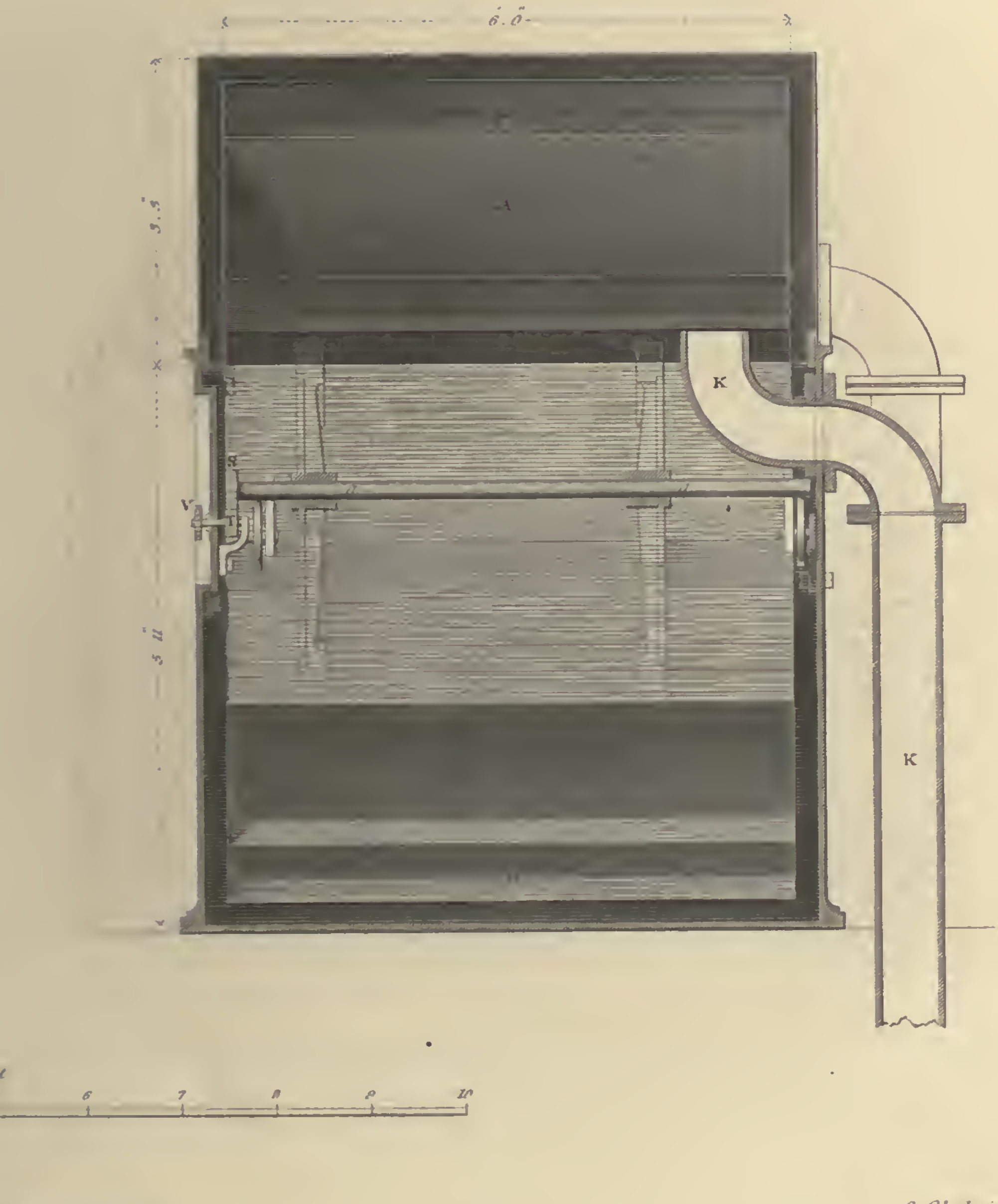
Plate X.

Fig 2



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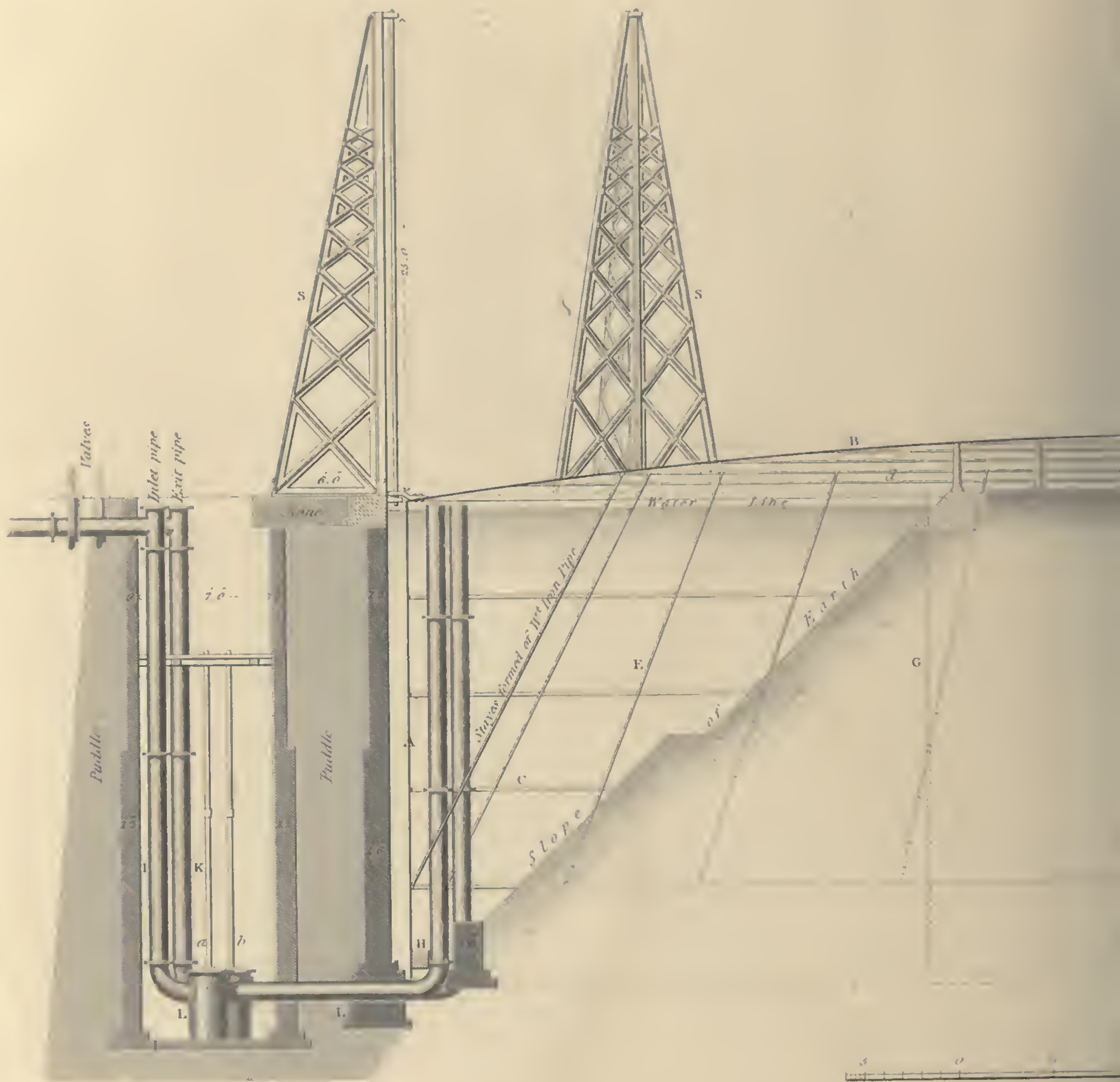
Section of a Gasometer

Diameter 87' 6" Height



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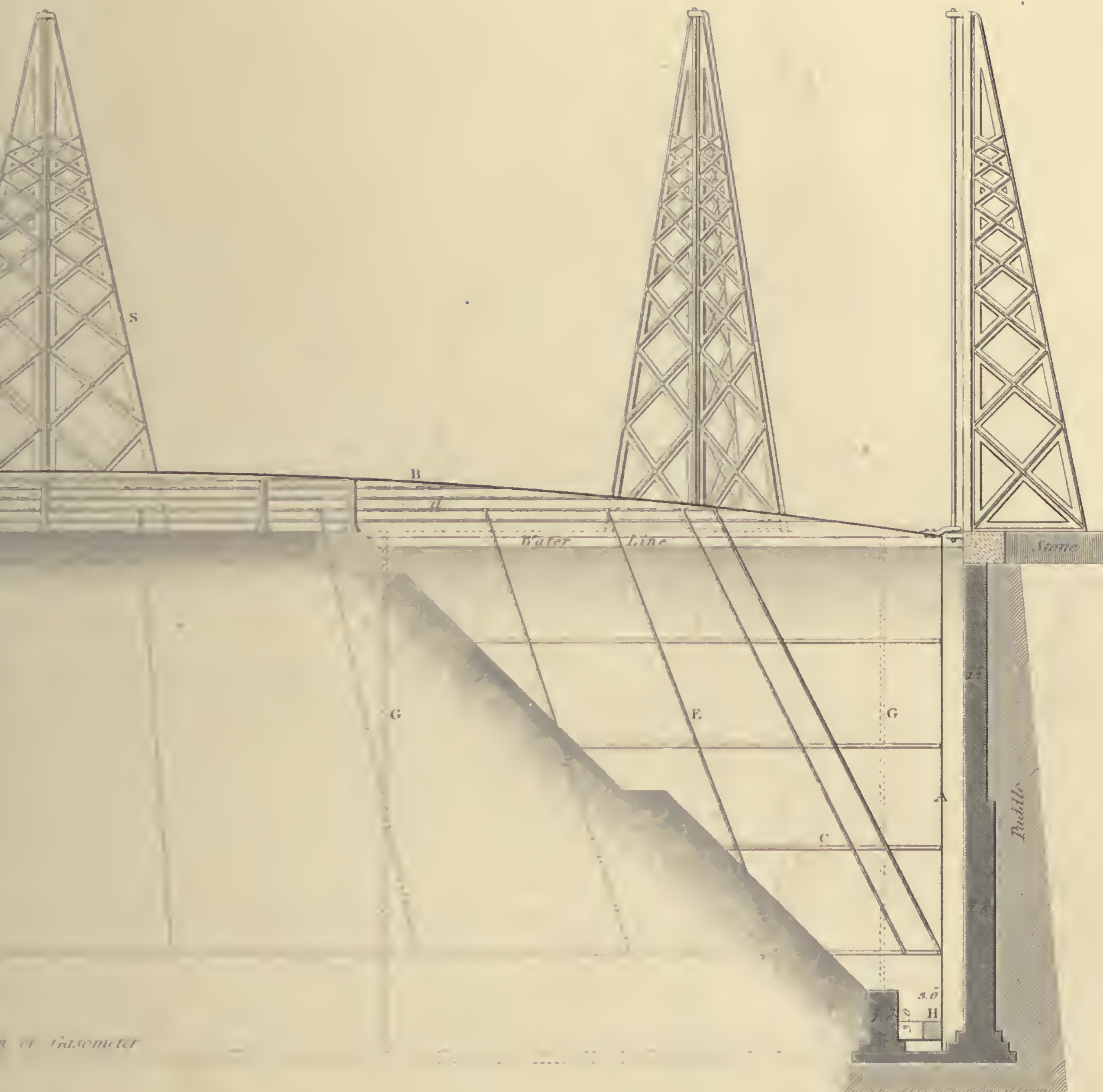

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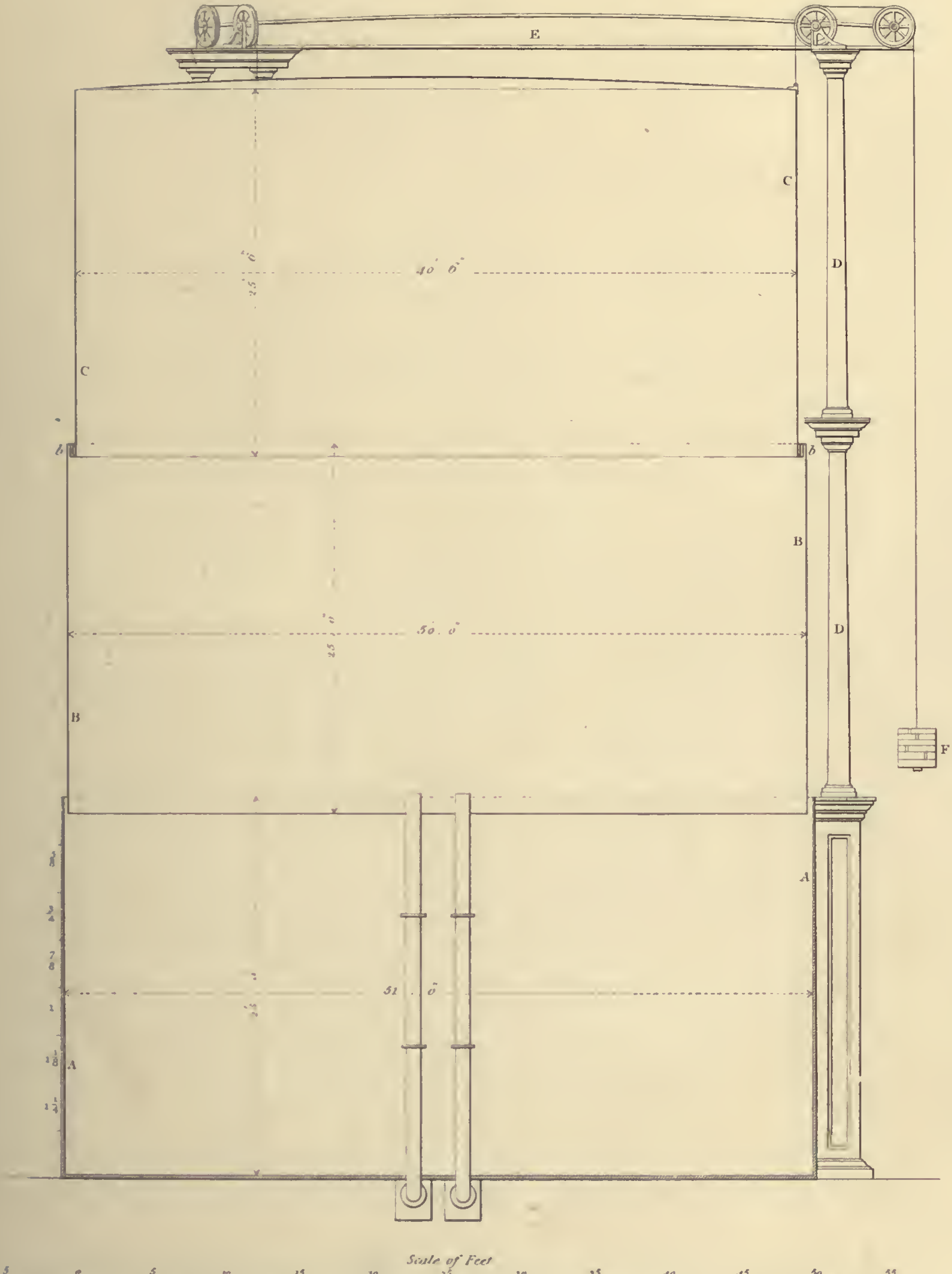

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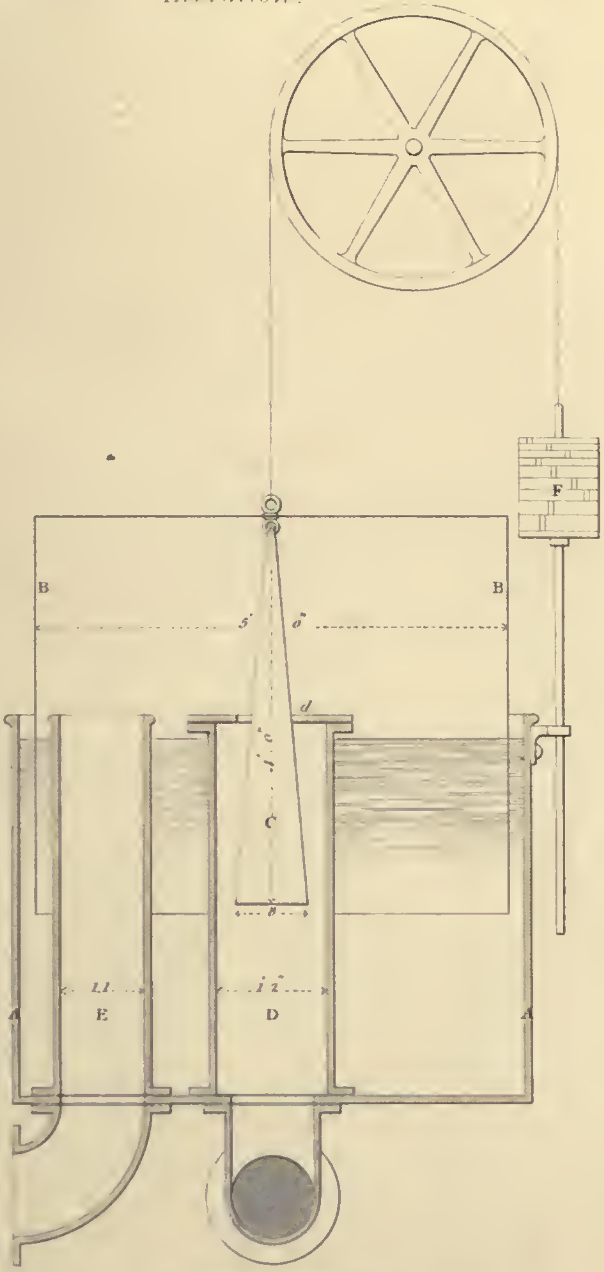
Elevation.



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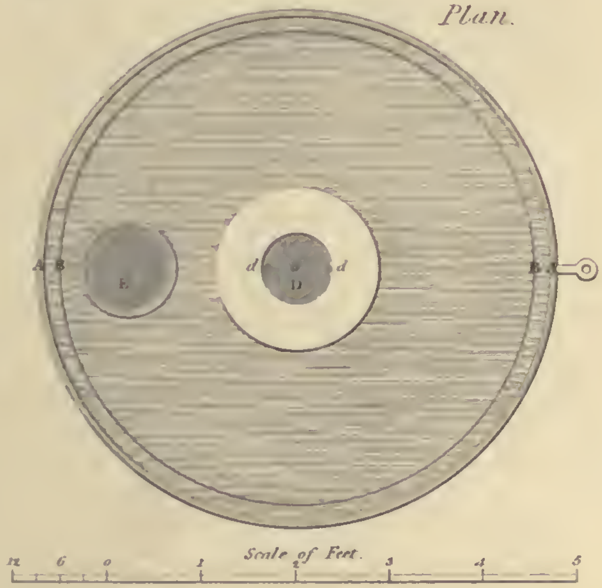

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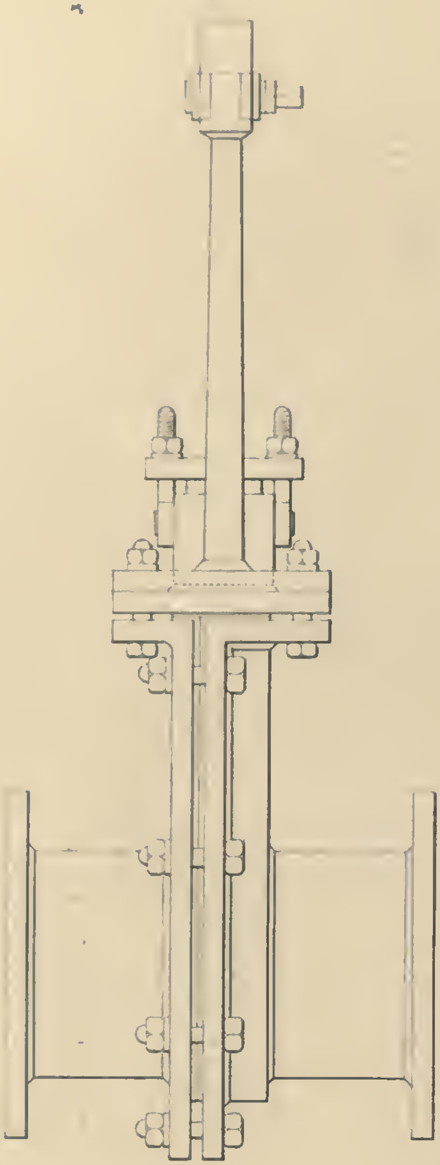
Fig 1



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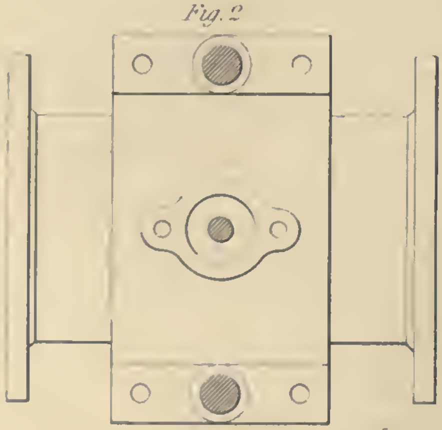

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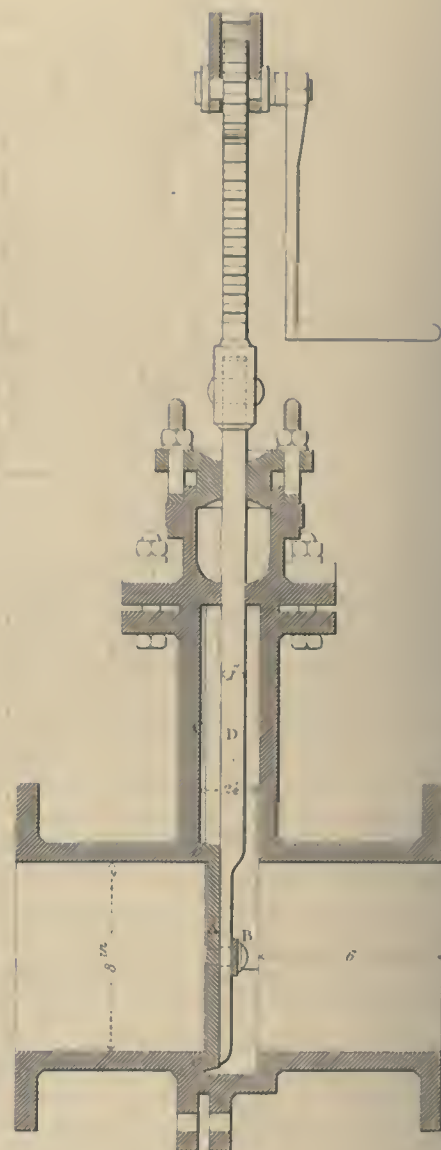

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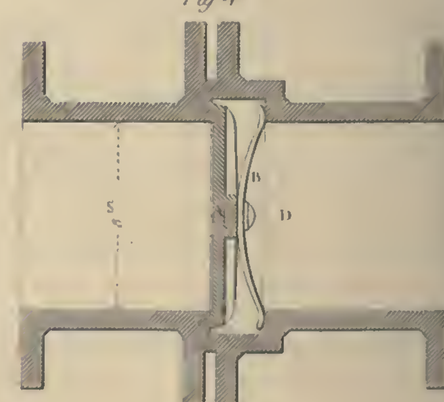

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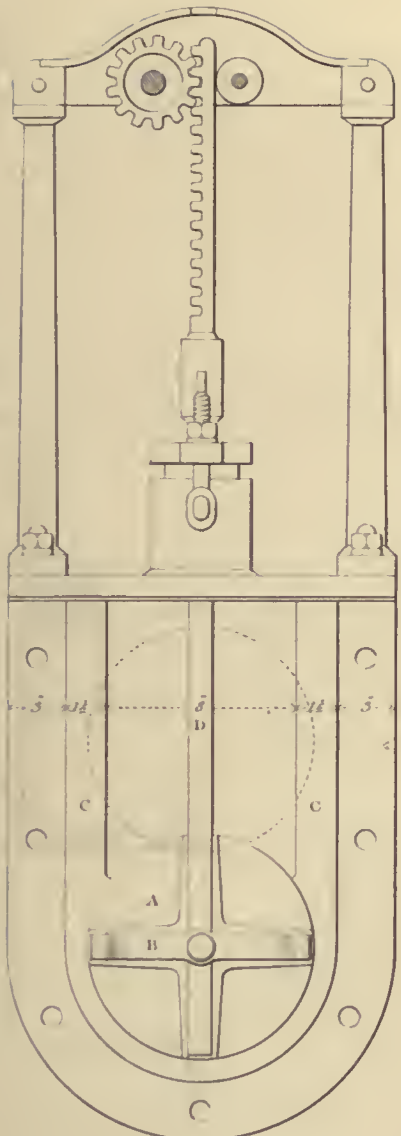

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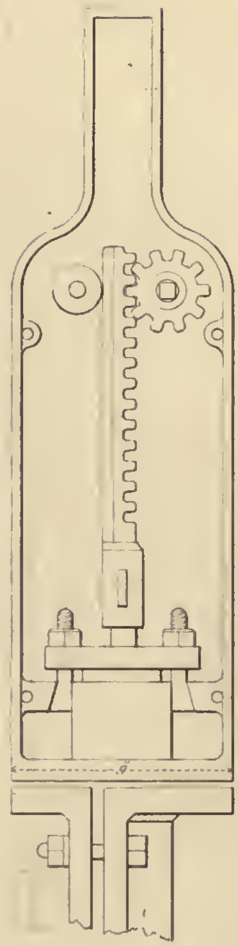

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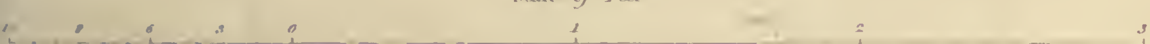
Scale of Feet



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